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NUMERICAL SIMULATION VERSION OF A RAILWAY TRACTION USING ASYNCHRONOUS MOTORS

Vasile Tulbure
Rodica Feştilă, Eva Dulf, Tiberiu Coloşi

Technical University of Cluj-Napoca
Faculty of Automation and Computer Science
Department of Automatic Control
Baritiu Str., 26-28, Cluj-Napoca
e-mail: Tiberiu.Colosi@aut.utcluj.ro

Abstract:This study is a sequel of the paper „Analog modeling variant of a railway traction by means of asynchronous motors".
A numeric integration software has been created and run on computer for the four asynchronous squirrel cage motors of a EC-43-3,6 MW electric locomotive, in a runing and sub-synchronous braking regime, specific to the railway traction.
The importance of maintaining the magnetic flux at nominal value (Ψ_N) has been underlined and emphasized through a case study, for a continuous upward-downward evolution of the supply three-phase voltage frequency.
The distance to be covered successively includes a gradient and a descent, in order to render evident the performance of the asynchronous motor under these conditions.

Keywords: railway traction, asynchronous motor, numerical simulation, state variables, frequency – voltage chronogram, forces, velocities, powers.

1. FUNCTIONAL DIAGRAM

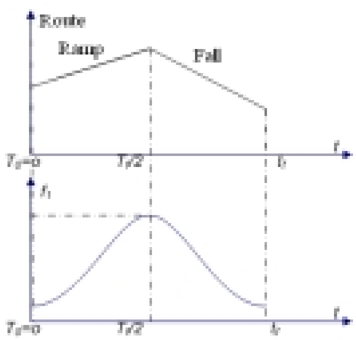

Figure 0

The numeric simulation was considered for an ascending (sin = 1/1000) and then descending (sin = -5/1000) railway run covered within the time period t_f= 900 sec, as shown in figure 1. The frequency's (f_1) dependence in relation to the time (t) for three-phase supply voltages (U_1) of the four asynchronous traction motors was expressed in the following forms $f_1(t) = f_{1min} + 0{,}5(f_{1max} - f_{1min})\cdot[1+\sin(2\pi/t_f.t-\pi/2)]$, setting out thus a symmetrical evolution in relation to the time moment ($t_f/2$). The frequency (f_{1min}) ensures the start by direct connection and the stopping by mechanical braking, respectively, while (f_{1max}) signifies the transition, at ($t_f/2$), from acclivity ascent to downhill descent.

The functional diagram of the numerical simulation, illustrated in figure 2 is simple and comprises 11 programme modules, as follows:

Module 1, comprises non-iterative initialisation instructions, for instance: motor electrical and mechanical parameters, for the towed railcar set, the covered run, the initial conditions and the coefficients defining the three state variables, the electrical and mechanical time constants, the frequencies (f_{min}) and (f_{max}), etc.

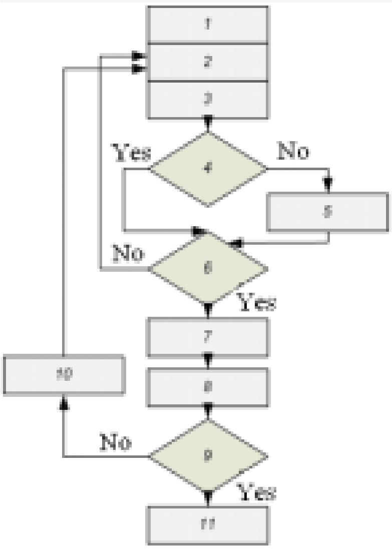

Figure 0

<u>Module 2</u>, comprises iterative initialisation instructions, e.g.: the frequency function $f_1(t)$, the calculation $U_1(f_1,S)$ according to (11)/[8], the calculation $u_1(t)$, as well as computations preparing the Taylor series, according to (15),…,(21),/[8].

<u>Module 3</u> provides the increment of the time with step (Δt) and the solving of the Taylor series.

<u>Module 4</u>, is a conditional branch instruction, maintaining the coefficient (ζ_0), valid for the ascending run, namely α=1/1000 if $t \le t_{f/2}$.

<u>Module 5</u> ensures the alteration of coefficient (ζ_0), valid for the downhill run, namely α=-5/1000, if $t > t_{f/2}$.

<u>Module 6</u> provides the iterative computation in modules 2 and 3, in case the moment (t) does not exceed the extraction period, iteratively incremented. In case (t) does not meet this condition, this conditional branch instruction transfers the computations to the next module.

<u>Module 7</u> performs the computation necessary for the signals intended to extract the data, in particular: torque, rotations, magnetization fluxes, currents, traction forces, time constants, velocities, powers and voltages ensuring the preservation of the magnetization flux at nominal values.

<u>Module 8</u> periodically extracts the signals computed in module 7.

<u>Module 9</u> ensures for $t \ge t_f$, the transfer to module 11 through the conditional branch instruction.

<u>Module 10</u> increments the signals' extraction moment by step ($\Delta\theta$), usually a sufficiently large multiple of the integration pitch (Δt).

<u>Module 11</u> provides the stoppage of the calculation if $t \ge t_f$.

Numerous numeric simulation variants have been run based on the functional diagram in figure 2.

2. OBTAINED RESULTS (MASQT11;12)

The following have been considered:

a) P_{1N}=900 kW; U_{1N}=1000V; f_{1N}=40 Hz; m_1=3; p_1=2; S_N=0,033; n_{1N}=1200 rot/min.
b) R_1=0,01Ω; X_1=0,1 Ω; R_m=0,9 Ω; X_m= 6 Ω; R'_2=0,01 Ω; X'_2= 0,1 Ω.
c) $\mathbf{x_1} = i_1$ [A]; $\mathbf{x_2} = i'_2$ [A]; $\mathbf{x_3} = \mathbf{\Omega}$ [rad/sec].
d) G_L = 80 [to]; G_R = 800 [to]; G_T == $G_L + G_R$.
e) sin α_{ascend}= 1/1000; sin α_{downh}= - 5/1000**<u>;</u>**
f) ρ_0 according to (6)/[8]; ρ_1 = 175 Nsec/m; ρ_2 = 20 $Nsec^2/m^2$
g) f_{min} = 5 Hz; f_{max} = 25 Hz
h) t_0-0; t_f= 900 sec; $\Delta t = 10^{-3}$ sec.

For this values, the results are : m_{MefN}= 7162 [Nm];
Ψ_N= 2,92 [Wb]; Tu=1/f_1=(1/40÷1/5) [sec]; T_{z1}=3,98.10^{-2} [sec];
T_{zm}= 2,65 .10^{-2} [sec]; $T_{z2}1$=1,3.10^{-3} [sec]; T_Ω= 513 [sec].; I_{1efN}=850 [A].

Table 1 presents the evolution in relation to the time (t), for a number of 15 signals, assuming the frequency $f_1(t)$ is according to [8], for the supply voltage $U_1(f_1,S)$ according to (11)/[8], ensuring the constant magnetization flux at the nominal value $\Psi_N = 2{,}92$ Wb.

The gradient run for sin $\alpha = 1/1000$ and then descending for sin $\alpha = -5/1000$ fits within the time limits between $t_0=0$ and $(t_f/2)$, and from $(t_f/2)$ to (t_f), respectively, for $t_f=900$ sec., according to figure 1.

At (tf/2), the train's movement speed and the power generated by the locomotive present nominal values, of 59,5 km/h, and 3082 kW, respectively.

It is noticeable the efficient braking effect sub-synchronous on downhill running, as a result of the continuous and slow decrease of the frequency in relation to the time, for which the differences of the slides, at symmetrical time moments (for instance between 360 sec and 540 sec etc.) gradually decreases by (0,002; 0,004; 0,005 and 0,001).

TABLE 1.

t_k	Sec	90	180	270	360	450	540	630	720	810	900
f_1	Hz	6,9	11,9	18,1	23,1	25	23,1	18,1	11,9	6,9	5
V_{1ef}	V	229	288	396	492	527	487	389	284	228	229
S_k		0,007	0,013	0,012	0,012	0,011	0,010	0,008	0,007	0,006	0,005
F_T	Tons	9,2	12,8	16,7	19,3	18,6	16,2	11,3	7,9	7,3	9,8
Velocity	Km/h	16,5	28,3	43	54,8	59,5	55	43,1	28,4	16,5	11,9
Power	kW	422	1009	1996	2946	3082	2485	1356	628	338	325
n_k	rot/min	205,6	353	535	684	741,6	685	538	354	206	149
m_{Mef}	Nm	4905	6820	7162	10278	9920	8655	7161	4227	3919	5211
Ψ	Wb		2,92			2,92				2,92	
I_{1ef}	A	321	446	586	677	663	589	438	329	290	313
I_{mef}	A	162	137	129	126	126	126	129	137	162	191
I_{2ef}	A	159	309	457	550	537	462	309	193	128	122
x_{1k}	A	326	483	659	463	-283	-1334	-371	233	58,6	-165
x_{2k}	A	-158	-442	592	349	-100	126	-392	37,1	-11.1	2,9
x_{3k}	rad/sec	21,5	37	56	71,6	77,6	462	56,3	193	21,6	15,6

Consequently for the, symmetrical time moments, the ascending run- and down hill run speeds are practically the same. This insensitivity of the speed despite of the great differences in the mode of operation of the traction motor is justified by the condition (11)/[8], which ensures the rated value of the magnetic flux at ψ_N=2,92[Wb].

Both the maximum traction force (19,3 to) and power developed by locomotive (3082 kW) remain in the admissible limits, i.e. 24[to] respectively 3600[kW]. It is to mention that the values ρ_1 = 175 [Nsec/m] and ρ_2 = 20 [$Nsec^2/m^2$] are maintained at constant values, but the coefficient ρ_0 is changed from $\rho_{0ascend}$=21.574[N] to ρ_{0downh}=-30.204[N] where the decrease of $\Delta\rho_0$=-51.778[N] is taken by the under-synchronous braking effect.

As it expected, the mechanical time constant T_Ω=513[sec] is much greater than the other time constant (T_{Z1}, T_{Zm}, $T_{Z2'}$), which are smaller than 4.10^{-2}[sec].

3. CONCLUSION

3.1 Numerical simulation using only the first four time-derivative of the Taylor series was kernel of the program MASQT11(12). The results obtained from this program are given in Table 1. The functional diagram from figure 2, connected to this program, is simple and flexible; it is possible to adapt easily for other categories of industrial asynchronous motors.

3.2. It was implemented a continuous dependence of the frequency (f_1) as function of time (t), in accord to figure 1, ensuring a symmetrical evolution of the ascending and descending values of the main variables, figure 1. It is possible to provide a valuable analysis of the asynchronous motor behaviour for various values of (t_f, f_{min}, f_{max}, etc) and characteristics of the railway run (ascend-downhill). Also, it is possible to analyse the under-synchronous ($s \geq 0$) and over- synchronous ($s \leq 0$) mode of operation of the traction motor.

3.3. Based on the program MASQT11(12), conceived for this aim, it is possible to study numerous fundamental problem and encountered in the railway-traction. As examples may be:

-selection of the values of the coefficients (ρ_0, ρ_1, ρ_2) from equation (5)/[8] for different trains and routes parameters;

-analysis of the braking mode of operation (for $s \geq 0$ or $s \leq 0$) not only by high speeds but also by law speeds, at the limits of the action of the mechanical brake;

-use of the function $\xi(t)$ from (11)/[8}, sub-unitary in the incipient phase of the train-start in order to diminish the starting electro-mechanical shocks;

-possibility to include the actual simulation program in analogical or digital control loops, using modern, advanced control algorithms.

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