EXCITATION OF OSCILLATION ON INPUT FILTER OF TRACTION VEHICLE WITH INDUCTION MOTOR

M. Lewandowski

Electric Traction Division, Warsaw University o Technology, Pl. Politechniki 1

00-661 Warsaw, Poland

Summary The phenomenon of oscillation created on input filter of traction vehicle with induction motor is analyzed here. Instability of the filter may occur especially in case when the receiver is responsible for the filter load and its power is maintained at constant level by fast control loops. The theoretical analysis and simulation studies revealed that the input inverter's filter oscillations may appear depending on the location of the vehicle in relation to the substation. Asynchronous motor control according to constant power algorithm under specific conditions may be the reason of vibrations.

1. INTRODUCTION

The phenomenon of oscillation created on input filter of traction vehicle with induction motor is analyzed here. The basic structure of the system adopted for the analysis are following: traction substation, input filter, inverter, induction motor controlled as per DCS method (direct self control) and mechanical system of transmission of torque from the motor into driving wheels of the traction vehicle. For this kind of model the differential equations describing the system do not reach linearity even after assuming constant rotor speed of the motor. This is the reason why the equations of state were linearalised around the defined working point and basing on this, the stability of the system has been analyzed [2]. If we select the parameters of the motor controller correctly then the analysis of the stability of the system carried out by the author proves that the system stability depends on the filter parameters and on the driving wheels spin. The analysis proves that the influence of parameters connected with the process of forming of oscillation within wheel-rails system has rather unimportant influence of the parameters of the filter oscillation [3]. The kind of filter used has significant influence on the stability of the driving system. Instability of the filter may occur especially in case when the receiver is responsible for the filter load and its power is maintained at constant level by fast control loops.

2. MATHEMATICAL DESCRIPTION OF SYSTEM'S ELECTRICAL PART

Input of the inverter is connected to over head catenary through low-band filter as per fig.1 The gamma type four-terminal network is used as a filter. The assignment of the input filter is to assure the proper parameters for the power electronics systems converting the electric energy (inverters), the filter also reduces current ripple rejection to the required level in order to assure the compatibility with the control and security systems of the railway traffic.

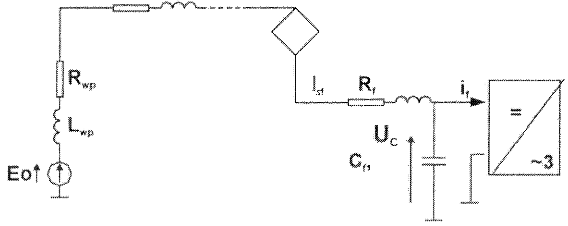

Fig. 1. Scheme o a circuit.

The dynamics of LC filter along with the supplementary model of traction substation and railway system (overhead catenary) is described below by the system of equations:

$$\frac{d}{dt}i_{sf} = -\frac{R_1}{L_1}i_{sf} - \frac{1}{L_1}u_c + \frac{1}{L_1}E_p \ , \quad (1)$$

$$\frac{d}{dt}u_c = \frac{1}{C_f}i_{sf} - \frac{1}{C_f}F \ . \quad (2)$$

Where:

F – function depending on the kind of load.

The resistance R_l corresponds with the resistance of supplementary traction substation R_{wp}, the resistance of the traction catenary (depending on the location of the vehicle on the route) and filter's resistance.

$$R_l=n_l(R_{wp}+R_{lin}(l))+R_f \tag{3}$$

Inductance L_l corresponds with inductance of supplementary traction substation L_{wp}, inductance of the traction catenary (depending on the location of the vehicle on the route) and filter's inductance.

$$L_l=n_l(L_{wp}+L_{lin}(l))+L_f \tag{4}$$

The coefficient n_l equals 4 and results from referring of the supplementary values of the power supply to the vehicle to one motor only. The remaining variables: E_0 traction substation input voltage, i_F- inverter's input current, i_{sf} – filter's and traction catenary current, u_c – voltage of capacitor (inverter's input voltage) , C_f – capacity of the filter's capacitor. The inverter is a kind of power electronic device with static and dynamic characteristics, which depend mainly on the type (kind) of controller and types of power electronic elements used. For the purpose of this analysis we assume that the power electronic elements have ideal characteristics. The function describing the input voltage of A, B and C phases of the inverter has the following form (5):

$$U_{(A,B,C)N}(t)=u_c(t)/2* K_{A,B,C} - u_c(t)/2 * \overline{K}_{A,B,C} \tag{5}$$

The value $K_{A,B,C}$ is generated by the controller, the voltage amplitude $U_{(A,B,C),N}$ depends on the value of potential across the capacitor C_f. The inverter input current is described as follows (6):

$$i_F(t) = i_A(t) * \mathrm{sign}(U_{AN}) + i_B(t) * \mathrm{sign}(U_{BN}) + i_C(t) * \mathrm{sign}(U_{BN}) \tag{6}$$

As a result of operation of fast control loops of motor current, increased input voltage u_c causes drop of the motor current and thus drop of the inverter current. This phenomenon is called the phenomenon of negative resistance. For the purpose of this analysis we assume that the filter's state of load is analyzed for the following three conditions:

a) - R_0 resistance load, $F=1/R_0$

b) - I_0 input current load, $F=I_0$

c) - P_0 constant power system load $F=P/u_c$

For the purpose of theoretical analysis we do not take into account the filter load caused by auxiliary equipment of the vehicle. For the purpose of describing of the filter stability it is convenient to write down equations 1, 2 in the form of equation of state 7.

$$\dot{x} = Ax + Bu \tag{7}$$

Where:

A – matrix of state $A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$

B – matrix of control $B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$

X – vector of state $x = \left[i_{sf} \quad u_c \right]^T$

u – vector of control $u = \left[u_1 \; u_2 \right]^T$

The system parameters independent of the kind of load

$$a_{11} = -\frac{R_l}{L_d},\ a_{12} = -\frac{1}{L_d},\ a_{21} = -\frac{1}{L_d}$$

$$b_{11} = \frac{1}{L_d},\ b_{12} = b_{21} = 0 \quad u_1 = E_p$$

The system parameters dependent on the kind of load:

a) $a_{22} = -\dfrac{1}{C_f R_0}, b_{22} = 0, u_2 = 0$

b) $a_{22} = 0,\ b_{22} = -\dfrac{1}{C_f}, u_2 = I_0$

c) differential equation describing the course of filter's capacitor voltage is of nonlinear characteristic and it has the following form

$$\frac{d}{dt}u_c = \frac{1}{C_f}i_{sf} - \frac{P}{C_f u_c} \tag{8}$$

The matrix of state A for this case was created for the linearized equation in the point U_{c0}, P_0.

$$a_{22} = \frac{P_o}{C_f U_{co}^2} \quad .$$

The analysis of stability is carried out through the analysis of eigenvalues of matrix of state A. The characteristic matrix has the following form:

$$\lambda^2 - \lambda(a_{11} + a_{22}) + a_{11}a_{22} - a_{12}a_{21} = 0 \quad . \quad (9)$$

The matrix eigenvalues have the following form:

$$\lambda_{1,2} = \frac{(a_{11} + a_{22}) \pm \sqrt{\Delta}}{2} \quad . \qquad (10)$$

For assumed range of parameters changes in case of traction vehicle $\Delta < 0$. Resulting from this the eigenvalues are found within set of complex numbers in the following form:

$$\lambda_{1,2} = \alpha \pm j\omega \qquad (11)$$

$$\begin{aligned} \alpha &= \frac{1}{2}(a_{11} + a_{22}) \\ \omega &= \sqrt{a_{11}a_{22} - a_{12}a_{21} - \tfrac{1}{4}(a_{11} + a_{22})^2} \end{aligned} \qquad (12)$$

The filter oscillations have an oscillatory character. The diminishing course of oscillations depends on the α parameter, while the pulsation depends on the ω parameter.

For conditions a and b the α parameter is expressed as below

$$\alpha_a = -\left(\frac{R_1}{L_d} + \frac{1}{C_f R_0}\right) \quad , \qquad (13)$$

$$\alpha_b = -\left(\frac{R_1}{L_d} + 0\right) \qquad (14)$$

and for each of system's parameters is less than zero. The filter oscillations have decreasing oscillatory character. In case of condition c the α parameter is expressed as follows:

$$\alpha_c = -\left(\frac{R_1}{L_d} - \frac{P_0}{C_f U_{c0}^2}\right) \qquad (15)$$

In case of condition c the value of α parameter may have positive as well as negative values. It depends on relations between the filter parameters and the power absorbed by the drive system. The power boundary value P_{gr} for the vehicle running with constant power may be calculated by equating the α_c parameter to zero.

$$P_{gr} = \frac{R_1 C_f U_{c0}^2}{L_d} \quad . \qquad (16)$$

Fig. 2 shows the course of power absorbed by the inverter, while fig. 3 shows the course of different values of potential across the capacity L_d and C_f. The increase of capacity as per fig.3b caused increased power which may be absorbed, whereas the increase of L_d as per fig.3c caused the decrease of boundary power P_{gr} for which the capacitor's voltage oscillations have diminishing oscillatory character.

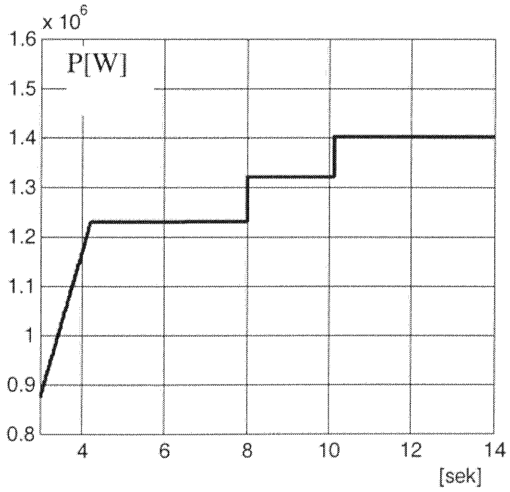

Fig. 2 The course of power absorbed by the inverter.

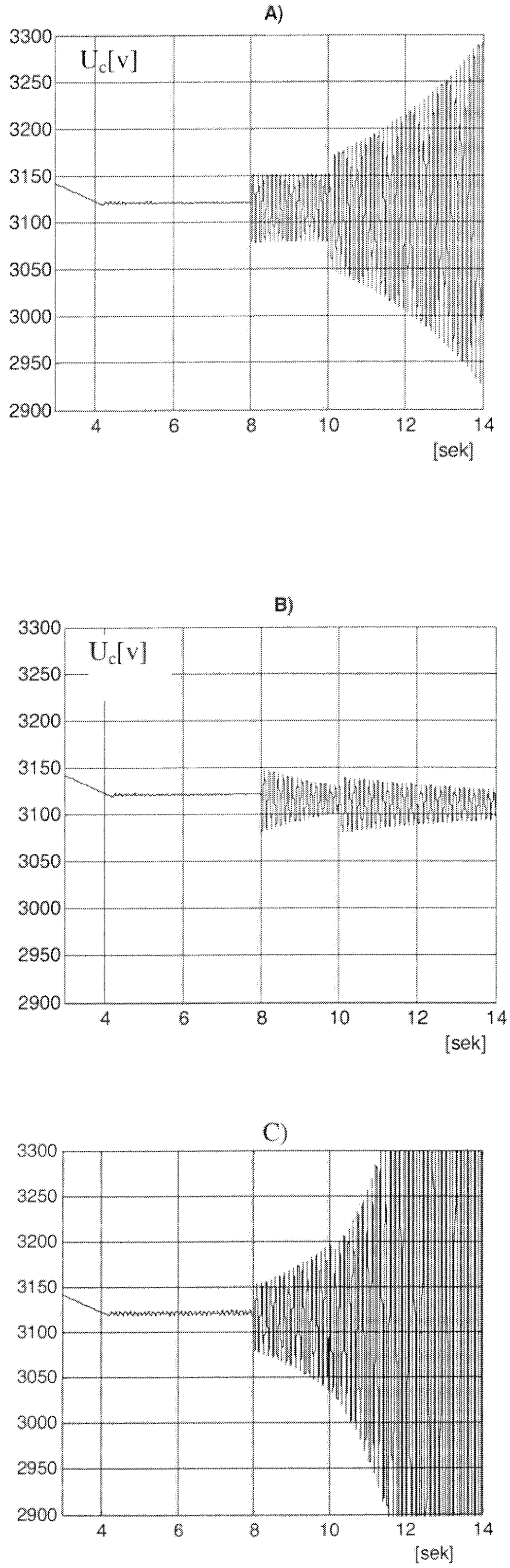

Fig 3 The course of voltage across the capacitor for:

A) $L_d=0.022\ [H],\ C_f=0.015\ [F]$

B) $L_d=0.022\ [H],\ C_f=0.015*1.1\ [F]$

C) $L_d=0.022*1.1\ [H],\ C_f=0.015\ [F]$

3. CONCLUSIONS

The theoretical analysis and simulation studies revealed that the input inverter's filter oscillations may appear depending on the location of the vehicle in relation to the substation. Asynchronous motor control according to constant power algorithm under specific conditions may be the reason of vibrations.

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