INFOTEH-JAHORINA Vol. 11, March 2012.

Efficiency Optimized Control of Elevator Drive

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***Abstract*—Model for efficiency optimization of electric elevator drive is presented in this paper. It combines two strategies for efficiency optimization: Loss model control and Search control. Search control technique is used in a steady state of drive and loss model during transient processes. As a result, power and energy losses are reduced, especially when load torque is significant less related to its rated value. This model is implemented in the control of real gear-less electric elevator drive with vector-controlled induction motor. Position trajectory is determined by the need that jerk is changed by the predefined function. Model of the drive is presented, and it is tested through computer simulations.**

Keywords-Electric elevator; Jerk control; Induction motor; Efficiency optimization; Loss model control; Search control

I. INTRODUCTION

The most common solution for vertical transport of passengers and goods in the residential and commercial buildings is an electrical elevator. Its construction is not substantially changed since the time when designed the first commercial elevators of this type. Control structures, safety elements, drive endurance and its durability and economy are constantly improved. Modern passenger elevators request high transport speed, low jerk, precise positioning, simple and efficient control and small number of sensors [1]–[3].

Particularly interesting in modern elevators is the energy efficiency. The evolution of the power digital microcontrollers and development of power electronics enables applying not only methods for induction motor drives (IMD) control, like vector control or direct torque control, but also development of different functions which make drives more robust and more efficient. One of the most interesting algorithm which can be applied in a drive controller is algorithm for efficiency optimization. Three strategies are usually used in efficiency optimization of IMD: Simple state control (SSC), Loss model control (LMC) and Search control (SC).

Drive loss model is used for optimal drive control in LMC strategy [3]–[5]. These algorithms are fast because the optimal control can be calculated directly from the loss model. But, power loss modeling and calculation of the optimal control can be very complex.

Search strategy methods have an important advantage compared to other strategies [6]–[9]. They are completely insensitive to parameter changes while effects of the parameter variations are very expressed in two other strategies. Algorithm is applicable universally to any motor. But for many applications flux convergence to its optimal value is too slowly.

Hybrid method combines good characteristics of two optimization strategies SC and LMC [9]. During transient processes LMC is used and SC is applied for efficiency optimization in a steady state of drive. Hybrid method obtains fast convergence to optimal flux and negligible sensitivity to parameter changes.

Organization of paper is as follows:

Loss model of induction motor in d-q rotational system is given in second section. Model which combines loss model controller and search controller is presented in third section. Description of the entire system configuration, elevator with drives and drive sheave is presented in third section, too. Qualitative analyses of this method with simulation results are given in fourth section. Obtain results are summarized in conclusions.

II. POWER LOSS MODELLING

The overall power losses in electrical drive consists of converter losses and motor losses, while motor power losses can be divided in copper and iron losses:

$$\begin{aligned} P_{tot} &= P_{mot} + P_{inv} \\ P_{mot} &= P_{Cu} + P_{Fe} \end{aligned} \tag{1}$$

Main constituents of converter losses are the rectifier, DC link and inverter conductive and inverter commutation losses. Overall flux-dependent losses are usually given by [4]:

$$P_{inv} = R_{inv} \cdot i_s^2 = R_{inv} \cdot \left(i_d^2 + i_q^2\right), \tag{2}$$

where i_d, i_q are components of the stator current i_s in d,q rotational system and R_{inv} is inverter loss coefficient.

The differentiation of total power losses, P_{tot}, in respect of i_{sd} for constant electromagnetic torque gives value of magnetizing current which obtains minimum power losses for a given operational conditions [11]:

$$\frac{\partial P_{tot}}{\partial i_{sd}} = 2R_a i_{sd} - 2R_b \frac{T_{em}^2}{k_{ekv}^2 i_{sd}^3} = 0$$

$$i_{sdLMC}^* = \sqrt[4]{\frac{R_b}{R_a} \frac{T_{em}^2}{k_{ekv}^2}}\,, \tag{3}$$

where i^*_{sdLMC} is reference value of magnetization current calculated in LMC, R_a and R_b are calculated from motor parameters [11], T_{em} is electromagnetic torque in rotor flux oriented reference frame witch is expressed as:

$$T_{em} = \frac{3}{2} P \frac{L_m^2}{L_r} i_{sd} i_{sq} = \frac{3}{2} P L_m^{'} i_{sd} i_{sq} = k_{ekv} i_{sd} i_{sq}, \tag{4}$$

where $k_{ekv} = 3/2 Z_p L_m^{'}$.

Search algorithm is used in steady state, which is detected in the steady state control (SSC) block. Error that exists between the current reference i_d that is generated in the LMC model and in the Search model appears as a consequence of parameter changes in the loss model as well as the stray losses which are not included in the model. The applied search algorithm is simple. Since the current i_{sd} is very close to the value which gives minimal losses small step of magnetization current Δi_{sd}=0.01i_{sdn} is chosen, where i_{sdn} is nominal value of i_{sd} current. For two successive values of the i_{sd} current, power losses are determined. Sign of Δi_{sd} is maintained if power losses are reduced. Otherwise, the sign of Δi_{sd} is opposite in the next step:

$$i_{sd}(n) = i_{sd}(n-1) - \mathrm{sgn}(\Delta P_{tot}(n-1))\Delta i_{sd}\,. \tag{5}$$

When the two values of magnetization current i_{ds1} and i_{sd2} were found so the sign of power loss is changed between these values new reference of i_{sd} current is specified as:

$$i_{sdSC}^* = \frac{i_{sd1} + i_{sd2}}{2}. \tag{6}$$

In this way, there are no oscillations of i_{sd} current, air gap flux and electromagnetic torque, which are characteristic of the search algorithm.

III. System Configuration

The analyzed elevator considers electrical drive and drive sheave that is mounted directly to the motor shaft without gear. Block diagram of the system is shown in Fig. 1. Elevator motor

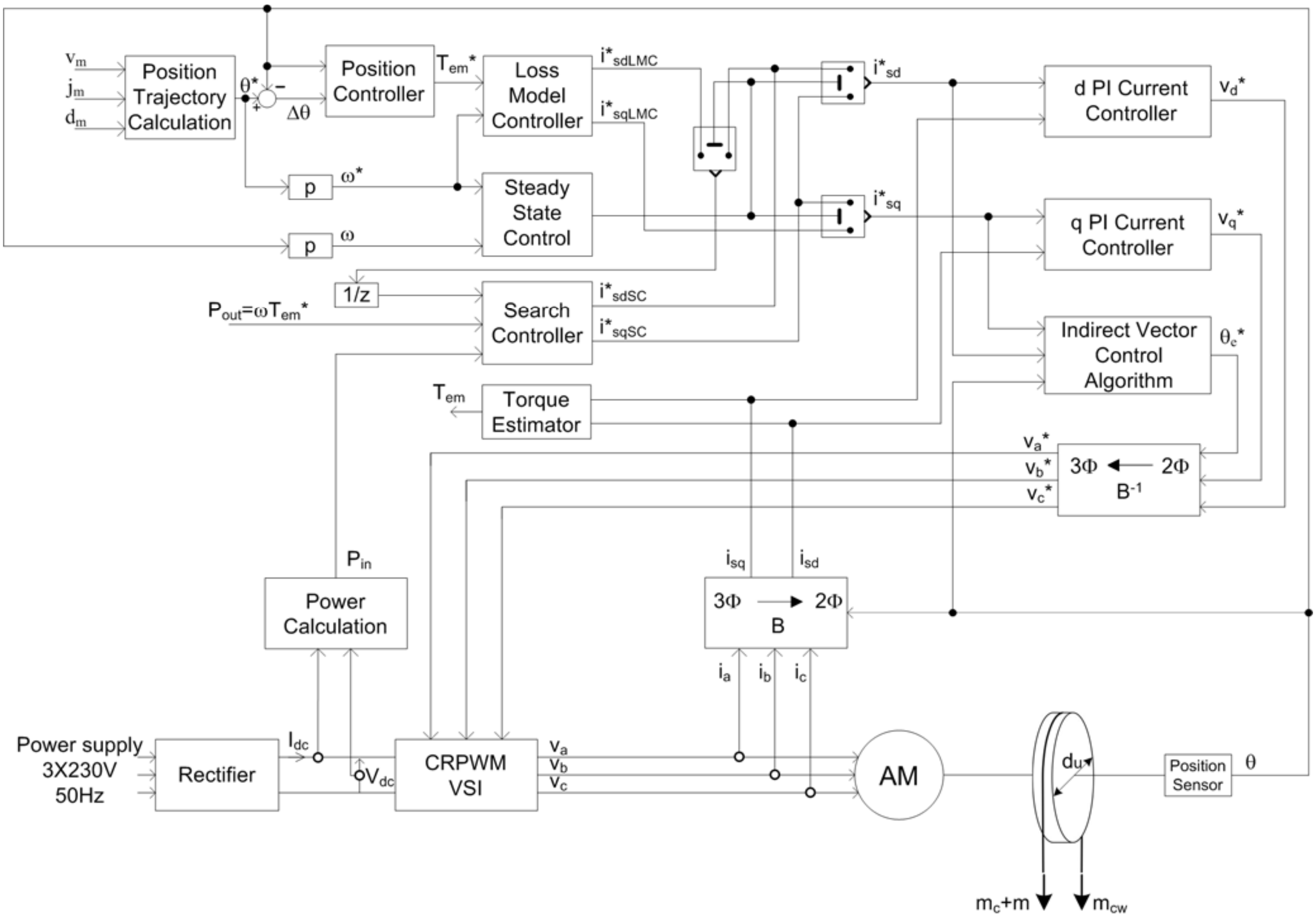

Figure 1. Block diagram of the efficiency optimized control of elevator drive with vector controlled induction motor and drive sheave that is mounted directly to the motor shaft without gear.

is three-phase asynchronous motor with squirrel cage induction motor (AM). Drive converter is current regulated PWM voltage source inverter (CRPWM VSI) direct current power supply. Indirect vector control algorithm (or Indirect Field Oriented Control, IFOC) where d, q rotational system is oriented toward rotor flux Ψ_r* is used for a control of drive.

Rotational movement of the motor shaft turns into linear movement over drive sheave directly mounted to motor shaft without gear box. The drive torque is transferred from the drive sheave by friction to the hoisting ropes that are connected to the car as counterweight. Weight of counterweight is m_{cw} [kg] (Fig. 1).

Drive sheave rotational speed is the same as rotational speed of motor shaft. Rotational and linear speed of car are related over radius of drive sheave. Load torque in the function of weight in the car can be calculated following the next expression:

$$T_L = \frac{d_u}{2} g \left(m - \frac{m_m}{2} \right), \tag{7}$$

where d_u [m] is diameter of sheave, m [kg] is a weight in car and m_m [kg] is elevator capacity. The total inertia is calculated as:

$$J_m = J_r + \left(2m_c + m + \frac{m_m}{2} \right) \left(\frac{d_u}{2} \right)^2, \tag{8}$$

where J_r is inertia of rotating masses (rotor, brake, sheave, etc.) and m_c [kg] is a weight of car.

Elevator is the positioning system and position controller is used for the task to provide position reference tracking and zero error in steady state. Constant load is usual for one elevator ride. So, a position controller with proportional, derivative and integral action (PID) is used [12].

Model for efficiency optimization (Fig. 1) consists form LMC, SC and Steady state control block (SSCB). LMC is used during transient states caused of external speed or torque demand [7]. Optimal control (i_{sdLMC}^*, i_{sqLMC}^*) is calculated directly from loss model for a given operating conditions. SC is used in a steady state, during constant speed of elevator.

IV. Simulation Results

Model of the system (Fig. 1) is verified through the computer simulations using the software package MATLAB/Simulink.

The reference position whose mathematical model is described in [12] is generated by S-function. Components of elevator drive and its control are described in sections III. The results are shown in Figs. 2., 3., 4. and 5. Input parameters for the dynamic of the elevator are:

--Final position of car: 20 [m],
--Nominal speed of car: 2 [m/s],
--Jerk amplitude: 4 [m/s^3],
--Elevator capacity: 900 [kg],
--Weight of the car: 400 [kg].

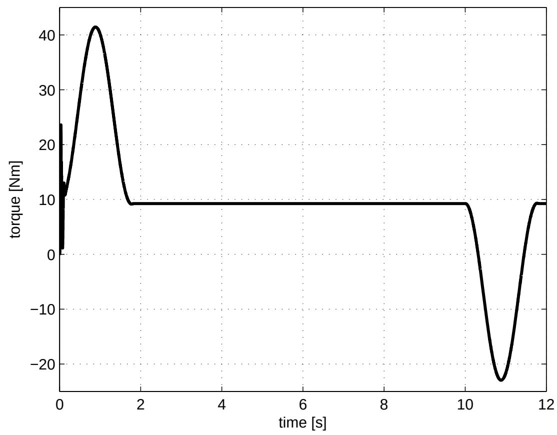

Figure 2. Torque of elevator drive with efficiency optimized control.

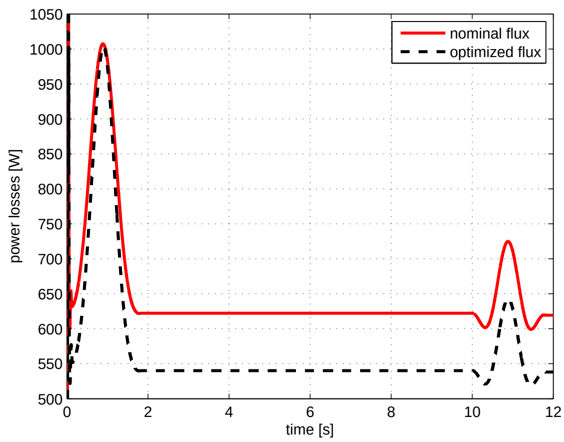

Figure 3. Power losses in elevator drive with efficiency optimized control and with nominal flux.

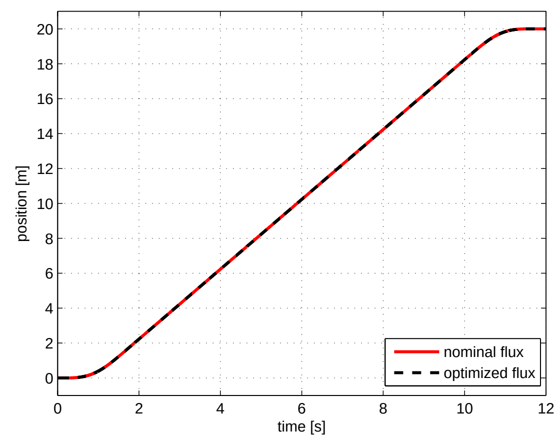

Figure 4. Position of the elevator car with efficiency optimized control and with nominal flux.

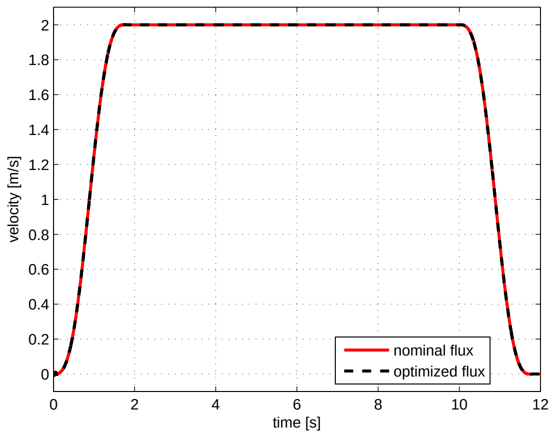

Figure 5. Velocity of the elevator car with efficiency optimized control and with nominal flux.

V. CONCLUSION

The paper describes efficiency optimization algorithm for electric elevator drive. Parameters of real elevator with induction motor drive were included in the model of elevator. Simulation of the entire system with designed efficiency optimization algorithm is made in the Matlab/Simulink.

According to the theoretical analysis and performed simulations at the following conclusions can be expressed. For a light load hybrid method for efficiency optimization gives significant power loss reduction (Fig. 3). Also, it shows good dynamic performances without loss of accuracy in position and velocity of the elevator car (Fig. 4 and Fig 5.)

Elevator drive is realized as vector controlled induction motor drive but similar efficiency optimization algorithm can be applied for other types of elevator drive permanent magnet synchronous motor (PMSM) drives, etc. Also, similar algorithm for efficiency optimization can be applied for other control technique in IMD, like Direct Torque Control (DTC). For vector control of IMD on the basis of flux and torque command , new values of control variables i^*_{ds} and i^*_{qs}., while in Space Vector Modulation (SVM) DTC new stator voltage vector is determined so that the desired change in flux and torque is achieved

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