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Dimensioning of a motor drive inverter for lift systems

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Abstract ***- This paper presents the development and practical enhancement of induction motor driving system used in lift. The fundamental operation of the induction motor drive hardware and software are introduced, and the different control techniques are described. Next, several issue related to dimensioning of drive system is considered. Lastly, this paper discusses practical problems in the realization of the lift system and represents a response to series of compromises and problems incurred during the process of designing, testing and servicing.***

Key words: ***lift system, drive system, lift inverter***

I. INTRODUCTION

Nowadays, lift systems have reached a relevant level of complexity and performances, and such a growth should continue its course in the future years. As such systems become more complex, efficient solving problems that accompany power supply, communications and software responsibility for providing functionality in these systems is becoming increasingly evident for the overall system performance. The goal of our research is to optimize the power supply and the drive system in respect to size, cost, reliability and energy efficiency by using modern control.

Developments in MCU performance are creating new opportunities for three-phase motor control solutions, which could lead to greater efficiency in everyday home appliances. On the other hand, industrial automation is synonymous with motion control, which is associated with images of sophisticated motor control circuits and it is a market that continues to grow.

Nowadays, in addition to *MCU*, *DSPs* and *FPGAs* are used more and more. They offer support and advantages in the field of precision and speed, which is needed in modern high-end inverters controls. The next very important advantage is the flexibility inherent in any digital controller, which allows to designer to modify the control strategy, or even to totally reprogram it, without the need for significant hardware modifications.

The two main types of lifts are traction and hydraulic and they described in [1]. In this paper the traction lift that use a driving motor that has to be controlled is in our focus. The motor component of the lift machine can be either a direct current (*DC*) motor or an alternating current (*AC*) motor. A *DC* motor has a good starting torque and ease of speed control. DC motors are used in special applications where high torque starting or smooth acceleration over a broad speed range is required. An *AC* motor is more regularly used because of its ruggedness and simplicity. A motor is chosen depending on design intent for the lift. Required power to start the cab in motion is equal to the power to overcome static, or stationary friction, and to accelerate the mass from rest to full speed. Considerations that must be included in the choice of an acceptable motor are good speed regulation and good starting torque. In addition, heating of various electrical components in continuous service should not be excessive.

Various alternatives of hoist motor drives include:

- *DC* motor drive with motor generator set (*DCMG*) or with solid-state controller (*DCSS*);
- *AC* - 2 speed motor drive;
- *AC* motor drive with variable voltage controller (*ACVV*);
- *AC* motor drive with variable voltage and variable frequency controller (*ACVVVF*);
- *AC* motor drive with vector control.

II. PRACTICAL PROBLEMS

The induction motor consists of an electromechanical system in which it is necessary to control various parameters, such as for example currents, voltages and speed. In practice, in order to use induction motors we have to exclude numerous issues such as:

1. When an induction motor starts, it will draws very high inrush current due to absence of the back *EMF* at start. The high inrush current may cause the voltage dip in the supply line, which may affect to performance of other utility equipment connected on the same supply line.
2. When the motor operates at a *PF* less than unity, the drawn current by the motor is not sinusoidal in nature. This condition degrades the power quality of the supply line and may affect to performance of other utility equipment connected on the same line.
3. While the motor operates, it is often necessary to stop it quickly and also reverse it. The torque of the motor drive has to be controlled so that the load does not have any undesirable acceleration.
4. The supply line may experience a surge or sag due to the operation of other equipment on the same line. If

the motor is not protected from such conditions, it will be subjected to higher stress than designed for, which ultimately may lead to its premature failure.

Previously mentioned potential problems related to *ACIM* let us to the conclusion that it is necessary to introduce an intelligent motor control.

III. ELECTRICAL, MATHEMATICAL AND MATLAB MODEL OF THE INVERTER AND MOTOR CONTROL

A typical inverter uses a simple rectifier front-end and a fixed voltage intermediate *DC* bus to help isolate mains current from that of the motor. The energy that a switching power converter delivers to a motor is controlled by *PWM* signals applied to the gates of the power transistors. Main focus of this paper is the back-end block and the selection of the induction motor according to the load in the system lifts.

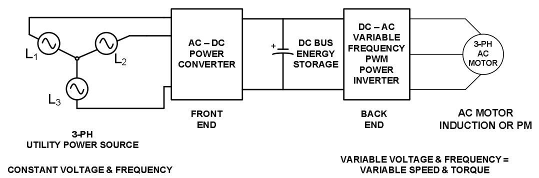

Fig. 1. Basic inverter control

Induction motors can be classified into two main groups:

- Single-phase induction motors. These only have one stator winding, operate with a single-phase power supply, have a squirrel cage rotor, and require a device to get the motor started.
- Three-phase induction motors. The rotating magnetic field is produced by the balanced three-phase supply. These motors have high power capabilities, can have squirrel cage or wound rotors and are self-starting.

The magnetic field created in the stator rotates at synchronous speed (N_s)

$$N_s = 60 \times f / p \tag{1}$$

where:

N_s - the synchronous speed of the stator magnetic field in *rpm*

p - the number of poles pairs on the stator

f - the supply frequency in *Hz*

However, in practice, the rotor never succeeds in "*catching up*" the stator field. The rotor runs slower than the speed of the stator field. This speed is called the base speed (N_b). Difference between N_s and N_b is called the slip and varies with the load.

$$\% slip = \left[\left(N_s - N_b \right) / N_s \right] \times 100 \tag{2}$$

where:

N_b - the base speed in *rpm*

A. Relationship between load, speed and torque

The following figure shows the equivalent circuit model of the induction motor block.

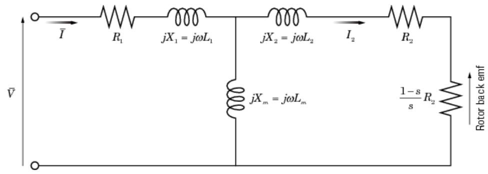

Fig. 2. Model of the induction motor

In the figure: R_1 is the stator resistance; R_2 is the rotor resistance with respect to the stator; L_1 is the stator inductance; L_2 is the rotor inductance with respect to the stator; L_m is magnetizing inductance; s is the rotor slip; $\overline{V}$ and $\overline{I}$ is the sinusoidal supply voltage and current phasors.

For an *n*-phase induction motor the torque-speed relationship is given by:

$$T = \frac{npR_2}{s\,\omega} \frac{V_{rms}^2}{\left(R_1 + R_2 + \frac{1-s}{s} R_2 \right)^2 + \left(X_1 + X_2 \right)^2} \tag{3}$$

where: V_{rms} is the line-neutral supply voltage for a star-configuration induction motor, and the line-to-line voltage for a delta-configuration induction motor: n is the number of phases; p is the number of pole pairs

The basic parameters of the *ACIM* type motor applied in practice are (2): type *FLS112M*, numbers of poles *4*, rated motor power output *4.0kW*, rated terminal supply voltage *230/400V Δ/Y*, rated supply frequency *50Hz*, rated speed *1462* min^{-1}, nominal sleep *2.54%*, rated torque *27.5 Nm*, rated current *8.4 A*, moment of inertia *0.012*kgm^2. The motor with the single cage rotor may be modeled by the following impedances in ohms per phase referred to the stator circuit:

$R_1 = 0.641\Omega$, $R_2 = 0.3\Omega$, $X_1 = \omega * L_1 = 0.75\Omega$, $X_2 = \omega * L_2 = 0.5\Omega$, $X_M = \omega * L_M = 26.3\Omega$

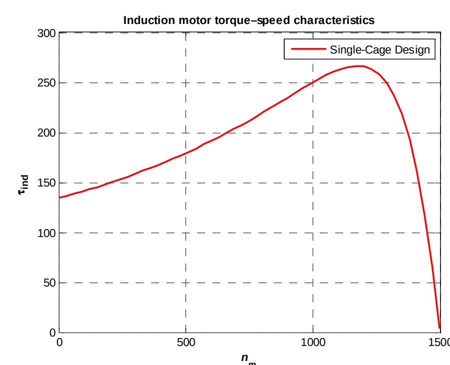

Fig. 3. Induction motor torque-speed characteristic supplied directly from the main supplay

IV. DIMENSIONING OF A DRIVE SYSTEM

Dimensioning of a drive system is a task where all factors have to be considered carefully. Dimensioning requires knowledge of the whole system including supply, driven machine, environmental conditions, motors and drives, etc. The general steps for dimensioning the motor and the frequency converter are the following:

1) First check the initial conditions
2) Check the process requirements
3) Select the motor
4) Select the frequency converter

A. Motor power

The motor's mechanical (output) power can be calculated from speed and torque using the formula:

$$P_{out}\left[W\right] = T\left[Nm\right] * \omega\left[rad/s\right] \quad (4)$$

Because motor power is most often given in kilowatts and speed in $rpm\left(1rpm = 2\pi/60\, rad/s\right)$, the following formula can be used:

$$P_{out}\left[kW\right] = \frac{T\left[Nm\right] * n\left[rpm\right]}{9550} \quad (5)$$

Electrical input power depends on voltage, current and power factor.

$$P_{in} = \sqrt{3} * U * I * \cos\varphi \quad (6)$$

The power factor tells us what proportion of the total electric power is active power and how much is so called reactive power. To produce the required mechanical power, active power is required. Reactive power is needed to produce magnetization in the motor.

The motor efficiency is the output power divide by the input power:

$$\eta = P_{out}/P_{in} \quad (7)$$

B. Rotational motion

One of the basic equations of an induction motor describes the relation between moment of inertia $\left(J\left[kgm^2\right]\right)$, angular velocity $\left(\omega\left[rad/s\right]\right)$ and torque $\left(T\left[Nm\right]\right)$. Equation is as follows:

$$\frac{d}{dt}\left(J\omega\right) = J\frac{d\omega}{dt} + \omega\frac{dJ}{dt} = T - T_{load} \quad (8)$$

In the above equation it is assumed that both the frequency and the moment of inertia change, what is the real situation. The formula is however often given so that the moment of inertia is assumed to be constant.

$$J\frac{d\omega}{dt} = T - T_{load} \quad (9)$$

Torque T_{load} represents the load of the motor. Motor torque can be considered as consisting of a dynamic and a load component.

$$T = T_{dyn} + T_{load} \quad (10)$$

The dynamic torque component caused by acceleration/deceleration of constant moment of inertia (J is constant, motor's speed is changed by $\Delta n\left[rpm\right]$ in time $\Delta t\left[s\right]$) is:

$$T_{dyn} = J * \frac{2\pi}{60} * \frac{\Delta n}{\Delta t} \quad (11)$$

C. Practical analysis

A lift system consists of a cab, a counterweight, gear and the motor-powered pulley. The cab and the counterweight are connected by a rope which is attached on the drum pulley. Weight of the cabin at idle mode is $1000\, kg$. General rule is that the counterweight equals the weight of the cab and attachments, plus $40\,\%$ of the rated capacity.

Thus, total mass to calculate the moment of inertia is $2400\, kg$. Based on the equation:

$$J = m * r^2 \quad (12)$$

Where is radius of the pulley $r = 0.5\, m$, we find that the moment of inertia is $J = 600\, kgm^2$.

The lift is intended to move at a nominal speed of maximum $1\, m/s$. In addition to the nominal, there are also speed service which is $1/4$ of the nominal speed, and speed leveling, 5% of the nominal speed. It is generally know that the relationship between linear speed and angular speed, for circular motion, is given like:

$$v = r * \omega \rightarrow \omega = v/r = 2\ rad/s \approx 20\, rpm\ .$$

In the presence of a gear, which is our case, the moment of inertia to the motor shaft has to be reduced. Gears are reduced from load side to motor side with following equations:

$$T_1 = \frac{T_2}{\eta} * \left(\frac{n_2}{n_1}\right);\ J_1 = J_2 * \left(\frac{n_2}{n_1}\right)^2 \quad (13)$$

The total moment of inertia of the system is:

$$J_{total} = J_1 + \left(\frac{n_2}{n_1}\right)^2 \left[J_2 + mr^2\right] = 0.12035\, kgm^2 \quad (14)$$

where is:

$J_1 = 0.012\, kgm^2$, $n_2/n_1 = 0.0133$,

$$J_2 = \frac{1}{2}mr^2\Big|_{\substack{r=0.5m \\ m=100kg}} = 12.5\, kgm^2,\ mr^2 = 600\, kgm^2$$

Motor nominal torque is:

$$T_n = \frac{9550 * 4}{1462}Nm = 26.1286\, Nm \quad (15)$$

Knowledge the load profile is essential when selecting a suitable motor and frequency converter for the application. Load torque consists of friction, inertia of the moving parts and the load itself. In order to derive the load torque equation it is assumed that the mass of the drive rope is ignored. The load torque T_{load} that is placed on the drive pulley which is mounted on the motor's shaft is expressed like

$$T_{load} = F_{load}\, r + J_{pulley}\ d\omega_m/dt \quad (16)$$

where: r - the radius of the drive pulley; J_{pulley} -inertia of the motor pulley; F_{load} - the force exerted on the drive pulley.

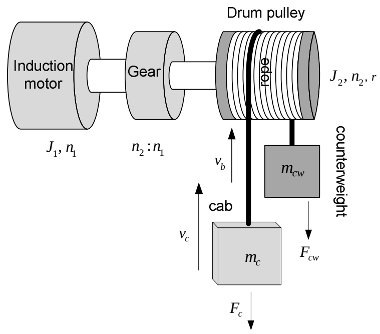

Fig. 4. Laboratory model of lift driven by *ACIM*

In the system, there are two directions of movement: upwards and downwards. If the lift cab is moving upwards the load torque is defined by:

$$T_{load-upwards} = r \cdot g \cdot (m_c - m_{cw}) + \frac{1}{2} r^2 \cdot m_c \frac{d\omega_{rotor}}{dt} + J_{pulley} \frac{d\omega_{rotor}}{dt}$$

The equation for load torque when the lift cab is moving downwards has the form:

$$T_{load-upwards} = r \cdot g \cdot (m_{cw} - m_c) + \frac{1}{2} r^2 \cdot m_{cw} \frac{d\omega_{rotor}}{dt} + J_{pulley} \frac{d\omega_{rotor}}{dt}$$

The starting time is calculated by dividing the speed range into five sectors. In each sector ($\approx 300\,rpm$) torque is assumed to be constant. Torque for each sector is taken from the middle point of the sector. The time to accelerate the motor with nominal torque from zero speed to the nominal speed can be calculated with formula:

$$\Delta t = \frac{2\pi}{60} * \frac{J_{tot} * \Delta n}{T_n - T_{load}} \qquad (17)$$

TABLE I

Acceleration times for the different speed section

$\Delta n[rpm]$	T_n / T_{load}	$\Delta t[s]$
300	0.99	0.1462
300	0.92	0.1573
300	0.78	0.1855
300	0.57	0.2539
300	0.29	0.4990

The total starting time is approximately $1.2419\,s$ which is within the boundaries of standard time.

D. Speed Control using V/f technique-simulation results

On the basis of previous analyzes and the obtained results we are in a position to examine the validity of techniques for speed control. The basic function of a variable speed drive is to control the flow of energy from the mains to the process. In constant open loop V/f control [4], by use of rectifier and *PWM* inverter, we can vary the supply voltage as well as the supply frequency such that the ratio remains constant so that the flux remains constant too. So we can get different operating zone for various speeds and torques and also we can get different synchronous speed with almost same maximum torque. Simulation results are shown in Fig.5. Frequency values are $10Hz$, $20Hz$, $30Hz$, $40Hz$ and $50Hz$.

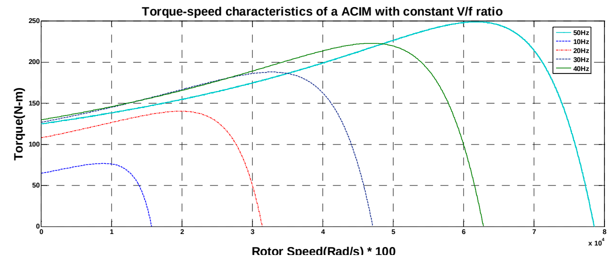

Fig.5. Torque-speed characteristics with constant V/f ratio

Also, it is important to consider ratio between voltage and frequency under the constant *V/Hz* principle.

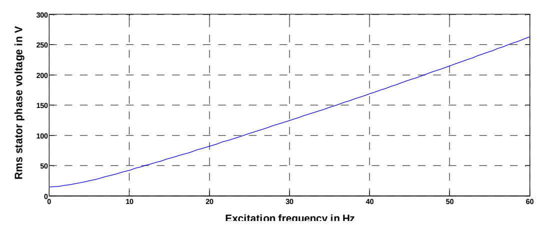

Fig.6. Voltage vs. frequency under the constant V/Hz

From the Fig.6., we can see that, when the frequency as well as the voltage are low, the voltage drop across the stator resistance cannot be neglected and must be compensated. This phenomenon is manifested in practice in the form of standstill of the cabin lift. Solution is involving the additional of a low frequency boost voltage.

VI. CONCLUSION

In this paper a design and dimensioning of a induction motor drive system for lift is presented. Special reference was given to open loop V/f speed control. Also, paper shows how various load torque characteristic can be generated by various frequency and voltage values generated by PWM signal. Results of analysis and simulations has successfully incorporated and applied in the practical realization of these blocks in the lift system.

REFERENCES

[1] A. Bhatia, Building Elevator Systems, Course No: A06-001, Continuing Education and Development, Inc.

[2] FLS totally enclosed three-phase asynchronous motors, http://www.leroy-somer.com/catalogue-industrie/fichiers/4-FLS-en.pdf

[3] ABB drives Technical guide book, http://www05.abb.com/global/scot/scot201.nsf/veritydisplay/56fa3d420a8e1483c12578b200484282/$file/technicalguidebook_1_10_en_revf.pdf

[4] TI Digital Motor Control Solutions, http://www.ti.com/lit/ml/sprb167a/sprb167a.pdf