THE OPERATION OPTIMIZATION OF AN INDUCTION MOTOR FED BY A PWM INVERTER

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1. ABSTRACT

At induction machines fed by a *PWM* inverters the permanent regime is formed of a succession of transitorous regimes that influence the characteristics of the machines that are for the optimization of the operation. In this paper I am discussing the operation optimization of a squirrel-cage induction motor for the steady-state operation. The motor functions on a voltage source inverter *PWM*.

2. INTRODUCTION

On this purpose the machine's stator is fed by a symetrical voltage systems. The iron loss is neglected. Equivalent circuit in T of squirrel cage induction motor is representend in fig. 1, end the mathematical equations in complex form is:

$$\underline{U}_1 = \underline{Z}_1 \cdot \underline{I}_1 - \underline{U}_{e1}; \quad 0 = R_2^{'} \underline{I}_2^{'} + j(\omega_1 - \omega) \cdot \underline{\Psi}_2^{'};$$
$$\underline{U}_{e1} = -\underline{Z}_{1m} \cdot \underline{I}_{01} = -j\omega \underline{\Psi}_1; \quad \underline{I}_{01} = \underline{I}_1 + \underline{I}_2^{'}, \qquad (1)$$

where

$$\underline{\Psi}_1 = L_{11} \underline{I}_1 + L_{sh} \underline{I}_2^{'}; \quad L_{11} = L_{\sigma 1} + L_{sh};$$
$$\underline{\Psi}_2^{'} = L_{sh} \underline{I}_1 + L_{22}^{'} \underline{I}_2^{'}; \quad L_{22}^{'} = L_{\sigma 2}^{'} + L_{sh}. \qquad (2)$$

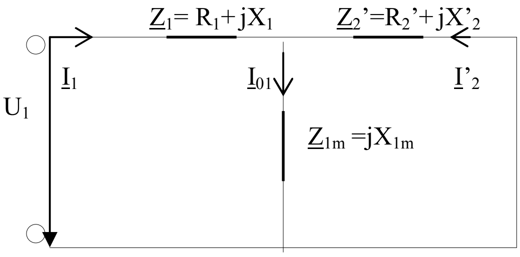


Fig. 1. T equivalent circuit of squirrel cage induction motor for steady-state operation.

Next, there is an presents a high efficient operation methods of an induction motor fed by a *PWM* inverter.

2. THE OPERATION OPTIMIZATION OF AN INDUCTION MOTOR FOR STEADY-STATE OPERATION

The speed control by variation in the source frequency f_1 is a high efficient method. All *PWM* inverters are used vary speed and operate with an ajustable frequency.

I discuss in the beginning the operation optimization of an induction motor at stator flux control. There is on study the scalar control and the flux vector control for the steady-state operation. The scalar control or U_1/f_1 control is a simple steady-state operation. For the source frequency $f_1 \leq 50\ Hz$, but approaches of *50 Hz*, the electromagnetic torque has the form:

$$M = \frac{pm_1}{\omega_1} \cdot \frac{R_2^{'} / s \cdot U_1^2}{\left(R_1 + R_2^{'} / s\right)^2 + \left(X_1 + X_2^{'}\right)^2}, \tag{3}$$

where X_1, X'_2 are determined at f_{1N}.

In (3) we place $\frac{U_1}{f_1} = \frac{U_{1N}}{f_{1N}}$ and the slip $s = \frac{f_1 - pn}{f_1}$, we obtain:

$$M = \frac{A(f_1 - pn)}{B + (f_1 - pn)^2 \cdot C}, \tag{4}$$

where: $A = \frac{m_1 p R_2^{'} U_{1N}^2}{2\pi f_{1N}^2}$; $B = R_2^{'2}$; $C = \left(\frac{X_1 + X_2^{'}}{f_{!N}}\right)^2$.

The speed is:

$$n = \frac{f_1}{p} - \frac{A \pm \sqrt{A^2 - 4BCM^2}}{2pCM}. \tag{5}$$

The characteristics *M=f(s)* are obtained of a *MatlabSimulink* scheme, and the characteristics *n=f(M)* are obtained of a *Matlab* programme.

For $f_1 > 50\ Hz$, at constant power, in expression (3) we put $U_1 = U_{1N}$ and we have:

$$M = \frac{A(f_1 - pn)}{f_1^2 \cdot \left[B + (f_1 - pn)^2 \cdot C\right]}, \tag{6}$$

where: $A = \frac{m_1 p R_2^{'} U_{1N}^2}{2\pi}$; $B = R_2^{'2}$; $C = \left(\frac{X_1 + X_2^{'}}{f_{!N}}\right)^2$. The speed is:

$$n = \frac{f_1}{p} - \frac{A \pm \sqrt{A^2 - 4BCM^2 f_1^4}}{2pCMf_1^2}. \tag{7}$$

The flux vector control is an efficient and dynamic method which has been discussed. That has more applications that will demand high performance speed and torque control.

In case of the stator flux vector control, in order to obtain the characteristics *M=f(s)* and *n=f(M)*, we introduce for $f_1 \leq f_{1N}$:

$$\Psi_{1N} = \frac{U_{1N}}{2\pi \cdot f_{1N}}, \tag{8}$$

because the induction motor is designed at nominal stator flux Ψ_{1N}. For $f_1 > f_{1N}$, the flux weckens.

We shall do the same for the operation of an induction motor at the air gap flux Ψ_{sh} control and the rotor flux Ψ_r' control, where we took into account that the machine operates in a stabil manner for:

$$\omega_2 \leq \frac{R_2^{'}}{L_{2\sigma}^{'}}, \tag{9}$$

where ω_2 is the flux rotor speed.

The variances of torque *M=f(s)* at flux vector control are obtained in of a *MatlabSimulink* block scheme. The block scheme has at base the structural schemes end these have at base the calculation expressions [1] in those three cases of flux vector control.

The stator current characteristics at flux vector control are determined in of a *MatlabSimulink* block scheme. It'is made up of the structural scheme which determines $I_1 = f(\omega_2)$ at $\Psi_1 = const$, $I_1 = f(\omega_2)$ at $\Psi_{sh} = const$, respectively the diagram which determines $I_1 = f(\omega_2)$ at $\Psi_r^{'} = const$. The structural schemes have at base the calculation expressions of the stator currents at $\Psi_1 = const$, at $\Psi_{sh} = const$ and at $\Psi_2^{'} = const$.

The obtained *MatlabSimulink* schemes are used at the study of the operation optimization of an induction motor fed by a *PWM* inverter.

3. THE OPERATION SIMULATION OF THE INDUCTION MOTOR FOR STEADY-STATE OPERATION

There will be token into account the performances the squirred-cage induction motor fed by a voltage source inverter. The motor has the parameters: P_N*=15 Kw*, U_N*=380/660V*, n_N*=1500 rot/min*. The study of the operation optimization of the induction machine is based on the *MatlabSimulinK* schemes, determined in the previous essay and also on a packet of programmes in *Matlab*.

The electromagnetic torque characteristics *M=f(s)* end the mechanical characteristics *n=f(M)* for $U_1/f_1=const.$, are presented in fig. 2 end fig. 3. The peak torque decreases with the frequency. At big frequencies, but approaches of *50 Hz*, the peak torques keep costant in large domain, so that the condition $U_1/f_1=const$ is practically favourable. At great frequencies $(f_1>f_{1N})$, the peak torques decreases end the machine works hard, especially at big shaft mechanical torque**.** At small frequences, $f_1<5$ *Hz*, because the maximum torque considerable decreases, the expression (3) is not available enymore. In this case, we have to use exact expressions [1], for the calculus of the command voltage at bornes, fig. 4.a, end of the electromagnetic torque, fig. 5.a.

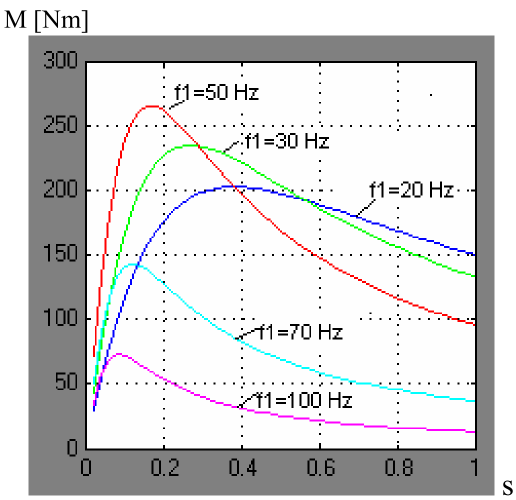


Fig. 2. Electromagnetic torque M=f(s) for U_1/f_1=ct., $f_1 \le f_{1N}$ end for $U_1=U_{1N}$, $f_1>f_{1N}$.

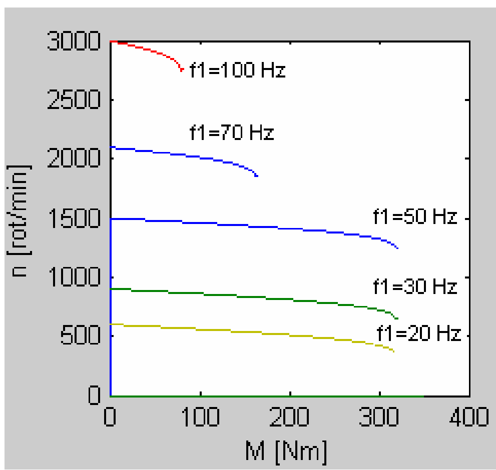
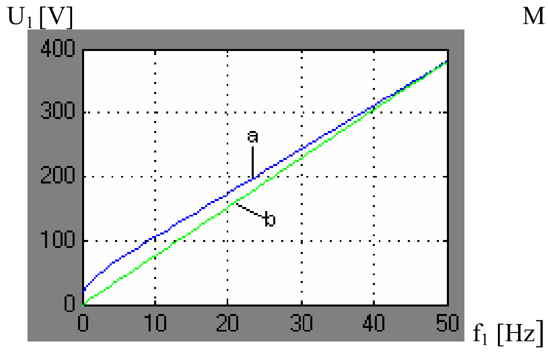


Fig. 3. The mechanical characteristics n=f(M) for U_1/f_1=ct., $f_1<f_{1N}$ end for $U_1=U_{1N}$, $f_1>f_{1N}$.



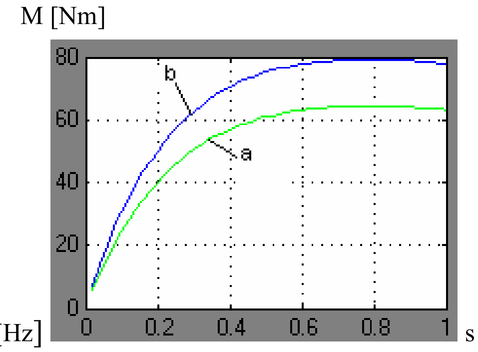


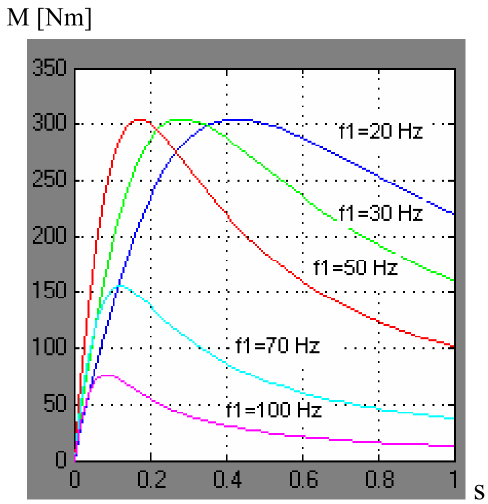
Fig. 4. The tension $U_1=f(f_1)$:
a. with the exact expression;
b. with the condition U_1/f_1=const.

Fig. 5. Electromagnetic torque M=f(s):
a. with the exact expression for f_1= 5 Hz;
b. with expression (3) for f_1=5 Hz.

The flux vector control at $\Psi_1=const$ is based on the flux stator control. The speed is to be controlled by variation in the source frequency f_1 simultaneous potential difference $\underline{U}_1$ or current $\underline{I}_1$. At different frequency the torque M is shown graphically in fig. 6, and speed in fig. 7.

The air gap flux $\underline{\Psi}_{sh}$ control is based on the exciting current $\underline{I}_{o1}$ control**.** The control $\underline{\Psi}_{sh}$ is reduced at the terminal voltage $\underline{U}_1$ control or the terminal stator current $\underline{I}_1$. The electromagnetic torque characteristics $M=f(s)$ end the mechanical characteristics $n=f(M)$ for $\Psi_{sh}=const$. are presented in fig. 8 end fig. 9.

The induction motor operation at constant rotor flux $\Psi_r'=const$ implies the existance of a liniar relation between speed and electromagnetic torque, fig. 10.



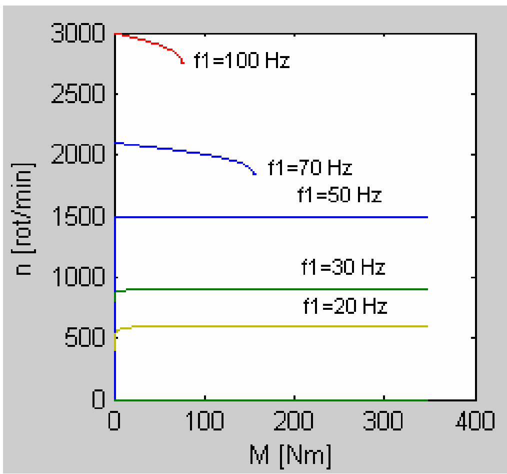


Fig. 6. Electromagnetic torques M=f(s) at Ψ_1 control.

Fig. 7. The mechanical characteristics n=f(M) at Ψ_1 control.

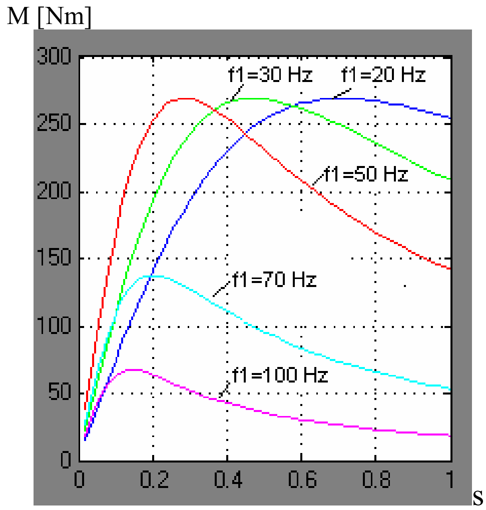


Fig. 8. Electromagnetic torques M=f(s) at Ψ_{sh} control.

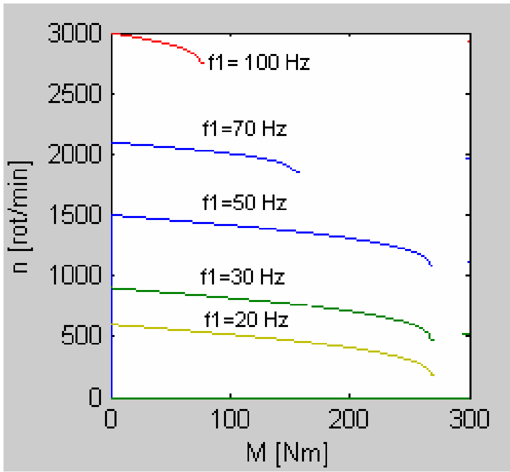


Fig. 9. The characteristics n=f(M) at Ψ_{sh} control.

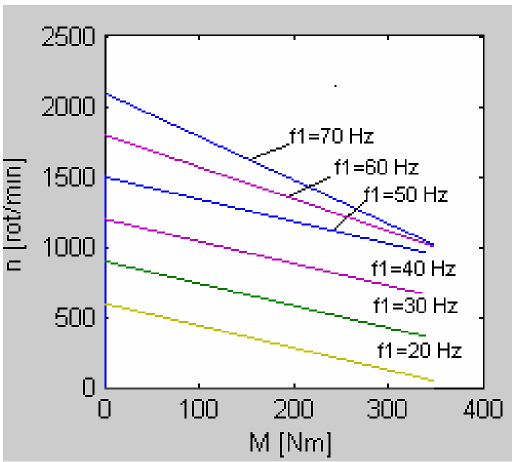


Fig. 10. The mechanical characteristics n=f(M) at Ψ_r' control.

In those three cases of flux vector control, the performances of the machine fed by a voltage source inverter, they can compare in the followy figures. The torques variation *M=f(s)* in those three cases is shown in fig. 11. The torques curves are determinated taking into account that this is stabil operate at $\Psi_{sh}=const.$ and $\Psi_r'=const.$ for (9).

The stator current characteristics $I_1/I_N=f(\omega_2)$ at flux vector control are presented in fig. 12. They allow to study the comparative operate of an induction machine in those three cases of flux vector control.

The biggest of an electromagnetic torque rates are at $\Psi_1=const.$ and the smallest rates at $\Psi_r'=const.$ In the last case the characteristics are liniar and ideal for dynamic control.

At the same rotor speed ω_2, with the condition (9), the biggest currents rates are obtained at $\Psi_1=const$, end the smallest current rates at $\Psi_r'=const$.

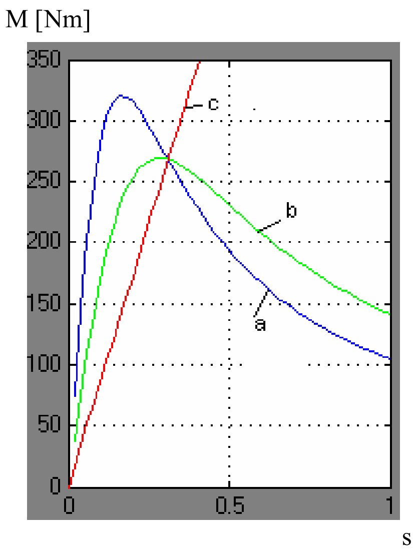


Fig. 11. The characteristics M=f(s) at flux vector control:
a. Ψ_1=ct; b. Ψ_{sh}=ct; c. Ψ_r'=ct.

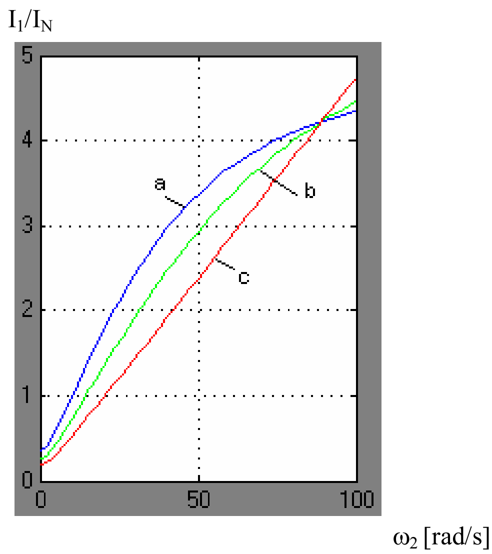


Fig. 12. The characteristics $I_1/I_N = f(\omega_2)$ at flux vector control:
a. Ψ_1=ct; b. Ψ_{sh}=ct; c. Ψ_r'=ct.

4. CONCLUSIONS

The scalar control $U_1/f_1=ct$. is used for the steady-state operation and the flux vector control for dynamic operation. For operation at a controlled flux end $f \leq f_{1N}$, the operation of the motor is done in accordance with the nominal stator flux Ψ_{1N}, end at bigger frequences the flux weckens. The maximum torque doesn't depend on the frequency. The control of the vector flux implies the control of the feeding tension or of the feeding current.

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5. **** Matlab, Language of Technical Computing, version 7, 2004.