Vector control structure of an asynchronous motor at maximum torque

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Abstract. Vector control methods offer the possibility to gain high performance, being widely used. Certain applications require an optimum control in limit operating conditions, as, at maximum torque, that is not always satisfied. The paper presents how the voltage and the frequency for an asynchronous machine (ASM) operating at variable speed are determinate, with an accent on the method that keeps the rotor flux constant. The simulation analyses consider three load types: variable torque and speed, variable torque and constant speed, constant torque and variable speed. The final values of frequency and voltage are obtained through the proposed control schemes with one controller using the simulation language based on the Maple module. The dynamic analysis of the system is done for the case with P and PI controller and allows conclusions on the proposed method, which can have different applications, as the ASM in wind turbines.

1. Introduction

Currently, the speed control on synchronous and asynchronous machine is performed by changing the frequency of the power supply, based on the fundamental relationship:

\[ n_1 = \frac{f_1}{p_1} \]  

where: \( f_1 \) – the frequency of the stator voltage; \( n_1 \) - rotating speed magnetic field of the stator and \( p_1 \) – represents the number of pole pairs [1].

As the number of pole pairs \( p_1 \) - is given by construction, results that the speed \( n_1 \) - can be only changed by modifying the frequency of the power supply. This frequency change can be achieved through various techniques [2] that use power electronics based on more efficient thyristors.

Different, complex, control methods of the asynchronous machine are proposed and analysed in different publications, with a difficult practical implementation [3], [4], [5]. The proposed method is simpler, presenting a high efficiency, as shown by the obtained results. All those control strategies require a real time monitoring system to provide a correct overview of the systems behaviour [8].

When only the frequency is changed, the voltage remaining unchanged, in the electric circuit with ferromagnetic coil, occurs the phenomenon of saturation of the ferromagnetic core, higher harmonic in current are reached and therefore the operation poses problems, both, to the supply system as to the machine that operates at variable speed [5].
2. Vector control scheme adjusting the voltage, frequency aiming the voltage variation

The control algorithm for ASM implements the speed [rpm] control by three different strategies: constant stator flux \( \Psi_s \), constant rotor flux \( \Psi_r \) and constant useful flux \( \Psi_u \).

For the proposed control strategies, two methods can be applied: first, the voltage at the controllers output is proportional to the speed error and the frequency is calculated from the condition of constant rotor flux and second, at the controller output we obtain a pulsation (i.e. stator frequency) proportional with the speed error and the voltage is computed, as in the first case, from the condition to maintain the rotor flux constant. Further, we present near the 1\( ^{st} \) method and the obtained results. From the general equation of the asynchronous machine, we obtain the structural scheme, Figure 1, control structure through voltage and frequency follows the voltage variations.

![Figure 1](image)

*Figure 1. Control structure through voltage and frequency follows the voltage variations*

The primary parameter is the stator voltage and the second parameter is the stator frequency. Through the controller, P or PI, the stator voltage is continuously changed proportionally to the error of the mechanical speed: \( \Delta \omega_{\text{mec}} = \omega^*_{\text{mec}} - \omega_{\text{mec}} \). The condition of constant rotor flux is achieved by changing by changing the stator frequency until reaching the prescribed speed, \( \omega^*_{\text{mec}} \), voltage and frequency are variable.

At the controllers (P or PI) output, we obtain a scalar value: \( \alpha \), sub-unitary, dependent on the value \( \Delta \omega_{\text{mec}} = \omega^*_{\text{mec}} - \omega_{\text{mec}} \). If the speed leap [rpm] is higher \( (\Delta n = n^* - n) \), \( \alpha \) will be higher too.

The speed control through by voltage, the scalar component \( \alpha \) is multiplied by the voltage \( U_s \), so that the stator voltage increases his value to \( U_s(1+ \alpha) \).
The stator frequency $f$ (i.e., pulsation $\omega$) is obtained from the stator voltage equation:

$$U \cdot (1 + a) - I_s R_s - \frac{d\psi_s}{dt} = j \omega \psi_s,$$

(2)

as it can be seen in the structural scheme given above.

The disturbing size – resistant torque $M_{rec}$, and the electromagnetic torque $M_{elmg}$, based on the movement equation

$$J \cdot \frac{d\omega_{mec}}{dt} = M_{elmg} - M_{rec},$$

(3)

will generate the mechanical angular velocity $\omega_{mec}$ [6]. The current value of $\omega_{mec}$ is compared with the prescribed value $\omega_{mec}^*$ resulting the error

$$\Delta\omega_{mec} = \omega_{mec}^* - \omega_{mec}.$$

(4)

This value (4) represents the input in the P or PI controller.

The rotor flux is given as value ($\psi_N$), and, therefore, it determines the stator flux $\psi_s$, stator current $I_s$ and then the electromagnetic torque [7]:

$$M_{elmg} = p_1 I_{mag} \left[ I_s \cdot \psi_s^* \right]$$

(5)

The proposed, simplified, control diagram block for adjusting the voltage, using a P or PI controller, is shown in Figure 2.

**Figure 2.** Control structure through voltage and frequency follows the voltage variations

3. **Control structure with the P-Type regulator**

The parameters of the asynchronous machine used in the implementing the simulation analysis, are:

- $L_1 = 0.1 \text{ H}$, $L_2 = 0.1 \text{ H}$, $M = L_a = 0.08 \text{ H}$, $R_1 = 5 \Omega$, $R_2 = 5 \Omega$, $p_1 = 1$, $\sigma = 0.36$, $L_{1a} = L_{2a} = 0.02 \text{ H}$, $1 - \sigma = 0.64$, $U_N = 380 \text{ V}$, $\psi_{N} = 1.2 \text{ Wb}$. The initial data, imposed by the technological process:
  - stator flux $\psi_s$ (from the construction data of the motor): $\psi_s = 1.2 \text{ Wb}$,
  - initial speed $n(0) = 2866.2 \text{ rpm}$ or $\omega_{m}(0) = 300 \text{ rad/s}$,
  - initial frequency $f(0) = 50 \text{ Hz}$,
  - rotor flux $\psi_r$ is obtained from the stator flux $\psi_s$. 


\[
\psi_r = \psi_2 = \frac{L_u}{L_i} \cdot \frac{R_2}{\sqrt{(R_e)^2 + (\omega, L_s \sigma)^2}} = 0.96 \text{[Wb]}.
\] (6)

The final parameters of the system, are:

- final speed \( n_{\text{final}} = 2960.4 \text{ rpm} \),
- final mechanical angular velocity = prescribed angular mechanical speed,
- from \( \omega = \omega_i + \omega_{\text{mec}} = 324 \text{ rad/s} \),
- stator frequency \( f = 51.568 \text{ Hz} \),
- final stator pulsation \( \omega_{\text{final}} = 324 \text{ rad/s} \),
- rotor flux \( \Psi_{\text{final}} = 0.96 \text{ Wb} \),
- final stator voltage \( U_{\text{final}} = 406.13 \text{ V} \),
- rotor angular frequency \( \omega_{\text{final}} = \omega - \omega_{\text{mec}} = 14 \text{ rad/s} \),
- final electromagnetic torque equal with the initial, 7.74 Nm.

The dynamic of the system analyzed by numerical simulations, assumes the evolution of the system from the initial voltage \( U \) and pulse \( \alpha \):

\( U(0) = 394.2 \text{ V} \), \( \omega(0) = 314 \text{ rad / s} \), \( f(0) = 50 \text{ Hz} \) to the final of values:

\( U(\infty) = 406.13 \text{ V} \), \( \omega(\infty) = 324 \text{ rad / s} \), \( f(\infty) = 51 568 \text{ Hz} \).

The control parameter based on the proposed control structure, Figure 2, is:

\[ \alpha = K \cdot (\omega_{\text{mec}} - \omega_{\text{mec}}) \] (6)

INITIAL: \( \omega = 314 \), \( \omega_i = 14 \), \( \omega_{\text{mec}} = 300 \)
FINAL: \( \omega = 324 \), \( \omega_i = 14 \), \( \omega_{\text{mec}} = 310 \).

In order that the control system, using a P-type regulator, has to reach the prescribed speed in a control period of \( T = 0.4[s] \), this will require a certain number of adjustments brought to voltage and frequency values.

For \( K = 1 \), the first adjustment range \( 0 - 0.4s \); initial: \( \omega_{\text{mec}} = W = 300 \text{ rad/s} \); voltage = 394.2 + 1(310 - W) = 404.2V.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Evolution in time of a) mechanical angular velocity and b) rotor flux}
\end{figure}

It is noted that for the first interval, the angular mechanical speed oscillates and reach a stationary value after 0.15s and the rotor flux also stabilizes in the same time, exceeding the nominal value. The final values, which consist the baseline for the next adjustment period, are: \( U(0.4) = -0.25881 \), \( Z(0.4) = -4.5883 \), \( Y(0.4) = 20.696 \), \( X(0.4) = 6.9209 \), \( \omega_{\text{mec}} = 304.73[\text{rad/s}] = W(0.4) \).

For a permissible error \( \Delta \omega_{\text{mec}} = 0.3[\text{rad/s}] \) the process is concluded, because \( \omega_{\text{mec}} - \omega_{\text{mec}} < 0.3 \), Figure 4. The adjustment period assumes seven intervals, a time of 2.8s.
Another studied case is that for the proportionality constant $K = 0.5$. After going through the control steps, as shown in the case $K = 1$, we obtain the general evolution of the pulse, in five adjustment periods, in a time of 2s, Figure 5.

Concerning the proportional controller $P$, of the equation $\alpha = K \cdot \Delta \omega_{mec}$, following conclusion can be drawn: the proportionality constant $K$ of the controller influence significantly the systems stability.

- at $K = 10$ and the inertial moment $J = 0.001$ [kgm$^2$], the system becomes unstable,
- at $K = 1$ and the same inertial moment $J = 0.001$ [kgm$^2$], the system is stable and the duration of the transient process is about 2.8s,
- at $K = 0.5$, the duration of the transitory process, at same $J$, is approximately 2s.

In order to achieve the prescribed speed, they are two possibilities:

- the control system provides periodic the voltage and frequency values and $K$ remains fixed,
- $K$ changes with the values of speed and resistant torque.

4. Conclusion
The proposed control scheme for the speed of the asynchronous machine (ASM) represents a modern solution for the automatic control for many electric drive systems, where a fast answer to the appeared perturbations is required.

The prescribed speed is achieved in an asymptotic way, by voltage adjusting, the frequency following the voltage variation, using a proportional controller. The proposed control scheme can be
also checked in other configurations, i.e. PI controller. Until the prescribed speed is reached, the rotor flux exceeds the nominal value that brings the motor function in the saturation regime.

The proposed control algorithm can be adapted in other control structure, as controlling the frequency and the voltage will follow the frequency variations. For future researches, we propose to compare the accuracy of different other control methods, applied in various domains such as wind power plants, and bring our contribution to improve their outcome.

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