Current State Regulator of Asynchronous Motor Commanded by Field Orientation

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Abstract **-The object of the present work is development and investigation of the current stator regulator of the asynchronous electromotor commanded by field orientation.**

The deviation of the current from the gives values in the state mode is reduced to zero using integrated regulators, separately for flux – determining $\underline{i}_{sd}$ and moment - determining $\underline{i}_{sq}$ component of the vector of the stator current $\underline{i}_s$ in the coordinate system synchronized with rotor fool magnetic flux.

Key words - **regulators, electro motors, vector current, stator current.**

I. Introduction.

One of the most modern methods to control the asynchronous electric motors is based on the determined type of field orientation [2]. In this case good dynamic of an electrical movement depends, first of all, on the chosen method for regulation of the stator vector current different components. Comparatively good results in the fixed work are received using different PI regulators in synchronous with field coordinate system [2]. The given discrete models for the state [1] allow the synthesis of different variants of vector regulators [4]. Another way, based on these models, is the regulation of the current in the space of the state.

The object of this report is the synthesis of such kind regulation circuit, synchronized with field coordinate system, named below with the term regulator of the current state.

II. Theory.

The generalized model of the controlled object is presented with Eq.1:

$$\underline{i}_s(k+1) = \underline{\Phi}_{11}\underline{i}_s(k) + \underline{\Phi}_{12}\underline{\psi}'_r(k) + \underline{H}_1\underline{u}_s(k) \quad (1)$$

where:
- $\underline{i}_s$ – is a vector of stator current;
- $\underline{u}_s$ - vector of the stator voltage;
- $\underline{\psi}_r$ - vector of the rotor fool magnetic flux, $\underline{\psi'}_r = \underline{\psi}_r / L_m$. ($L_m$ is a manual inductance).

The matrices $\underline{\Phi}_{11}$, $\underline{\Phi}_{12}$ and $\underline{H}_1$ are expressed using the parameters of T form equivalent circuit of the electric motor in the synchronized with field coordinate system according the Eq. 2 ÷ 4:

$$\underline{\Phi}_{11} = \underline{\Phi}_{11}^{1} = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix} = \begin{bmatrix} 1 - \frac{T}{\sigma}\left(\frac{1}{T_s} + \frac{1-\sigma}{T_r}\right) & \omega_s T \\ -\omega_s T & 1 - \frac{T}{\sigma}\left(\frac{1}{T_s} + \frac{1-\sigma}{T_r}\right) \end{bmatrix} \quad (2)$$

$$\underline{\Phi}_{12} = \underline{\Phi}_{12}^{f} = \begin{bmatrix} f_{13} & f_{14} \\ f_{23} & f_{24} \end{bmatrix} = \begin{bmatrix} \left(\frac{1-\sigma}{\sigma}\right)\frac{T}{T_r} & \left(\frac{1-\sigma}{\sigma}\right)\omega' T \\ -\left(\frac{1-\sigma}{\sigma}\right)\omega' T & \left(\frac{1-\sigma}{\sigma}\right)\frac{T}{T_r} \end{bmatrix} \quad (3)$$

$$\underline{H}_1 = \underline{H}_1^{f} = \begin{bmatrix} T/\sigma L_s & 0 \\ 0 & T/\sigma L_s \end{bmatrix} \quad (4)$$

where:
- T – duration of the fact;
- T_r – time constant of the rotor;
- T_s – time constant of the stator;
- ω' – electric angle speed of the rotor. If the mechanic angle speed of the rotor is ω' and the number of the couple poles of the motor is z_p, it means $\omega' = z_p\,\omega$.

The coefficient σ is presented by the Eq. 5:

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \quad (5)$$

where:
- L_s – inductance of the stator;
- L_r – the rotor's inductance.

From the model [1] for the stator voltage gives:

$$\underline{u}_s(k) = \frac{1}{\underline{H}_1}\left[\underline{i}_s(k+1) - \underline{\Phi}_{11}\underline{i}_s(k) - \underline{\Phi}_{12}\underline{\psi}'_r(k)\right] \quad (6)$$

If the part dependant on the current in the Eq. 6 is separated as an output factor for the designed regulator, of means that for the stator voltage the equation is validated:

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$$\underline{u}_s(k) = \frac{1}{\underline{H}_1}\left[\underline{y}(k-1) - \underline{\Phi}_{12}\underline{\psi}'_r(k)\right] \qquad (7)$$

Than for the output factor of the current state regulator the equation is:

$$\underline{y}(k-1) = \underline{i}_s(k+1) - \underline{\Phi}_{11}\underline{i}_s(k) \qquad (8)$$

Using Laplas transformation for discrete signals the Eq. 8 will have a form:

$$z^{-1}\underline{y}(z) = \left(z\underline{I} - \underline{\Phi}_{11}\right)\underline{i}_s(z) \qquad (9)$$

where I is single matrices.

The generalized block circuit of the current state regulator is given in Fig. 1, where $\underline{\mathbf{i}}^*_s(k)$ is a vector of the determined value of the stator's current.

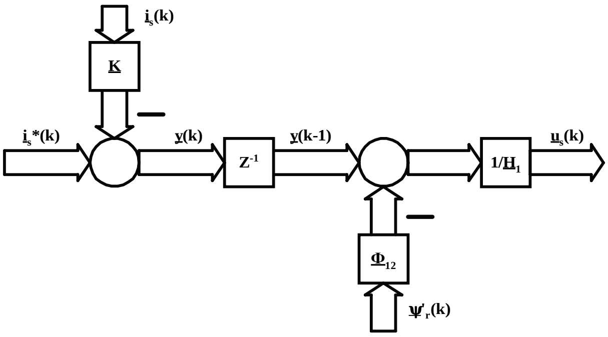

Fig. 1.

In accordance with the circuiting Fig. 1 for the output factor $\underline{y}(k)$ for the designed state regulator is obtained:

$$\underline{y}(k) = \underline{i}^*_s(k) - \underline{K}\underline{i}_s(k) \qquad (10)$$

where K is a reflexive regulation matrices and it determination is the goal of this work. In Z – area from the Eq. 10 follows:

$$\underline{y}(z) = \underline{i}^*_s(z) - \underline{K}\underline{i}_s(z) \qquad (11)$$

The matrices K must be determined is such away to realize the desirable dynamic behavior of the system, expressed by Eq. 12 [14]:

$$\underline{i}_s(z) = z^{-2}\underline{i}^*_s(z) \qquad (12)$$

The Eq. 12 shows the regulator transmission function in relation with the given regulated factor and it describes that, the real value mast reach the substitution of Eq. 12 in Eq. 11 and after than Eq. 11 in Eq. 9 the result is:

$$\underline{\Phi}_{11} - \underline{K}z^{-1} = \underline{0} \qquad (13)$$

That, for the reflexive regulating matrices the equation is:

$$\underline{K} = z\underline{\Phi}_{11} \qquad (14)$$

After the substitution of Eq. 14 in Eq. 11 for the output vector of the designed regulator, the z - area is:

$$\underline{y}(z) = \underline{i}^*_s(z) - z\underline{\Phi}_{11}\underline{i}_s(z) \qquad (15)$$

The Eq. 15 in the time area is:

$$\underline{y}(k) = \underline{i}^*_s(k) - \underline{\Phi}_{11}\underline{i}_s(k+1) \qquad (16)$$

Disadvantage of the above describe method for formation of the commanding effect $\underline{\mathbf{y}}$ is the residual current deviation $\underline{\mathbf{x}}_w$ in the settled mode. This problem could be removed using additional integrated regulators, as it is shown in Fig. 2.

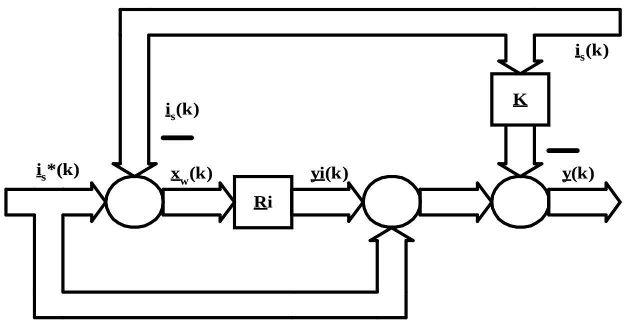

Fig 2. $\underline{x}_w(k)$ is the stator current deviation from the set value; $\underline{R}_i$ and $\underline{y}_i(k)$ are integrated regulator with its output factor.

The output factor of the state regulator in this case is given by Eq. 17, and for the integrated regulator by Eq. 18:

$$\underline{y}(k) = \underline{i}^*_s(k) - \underline{\Phi}_{11}\underline{i}_s(k+1) + \underline{y}_i(k) \qquad (17)$$

$$\underline{y}_i(k) = \underline{V}_i\underline{x}_w + \underline{y}_i(k-1) \qquad (18)$$

Where $\underline{V}_i$ gives the amplifying parameters of the integrated regulators. In this situation, according the above explained, the regulation of the current in the state space could be realized with next steps:

1. Calculation the value of the stator current $\underline{i}_s(k+1)$ is for one tact before using the model (Eq. 1) where the values $\underline{u}_s(k)$ and $\underline{i}_s(k)$ are derived from measurements, and $\underline{\psi}'_r(k)$ is given using a model with input values measured current and turns revolutions [1, 4];
2. Calculation the integral parts using Eq. 18;
3. Forming the output factor of the state current regulator according to an Eq. 17. The received values is memorized for one tact and it is used for calculation of the stator voltage in the next tact;

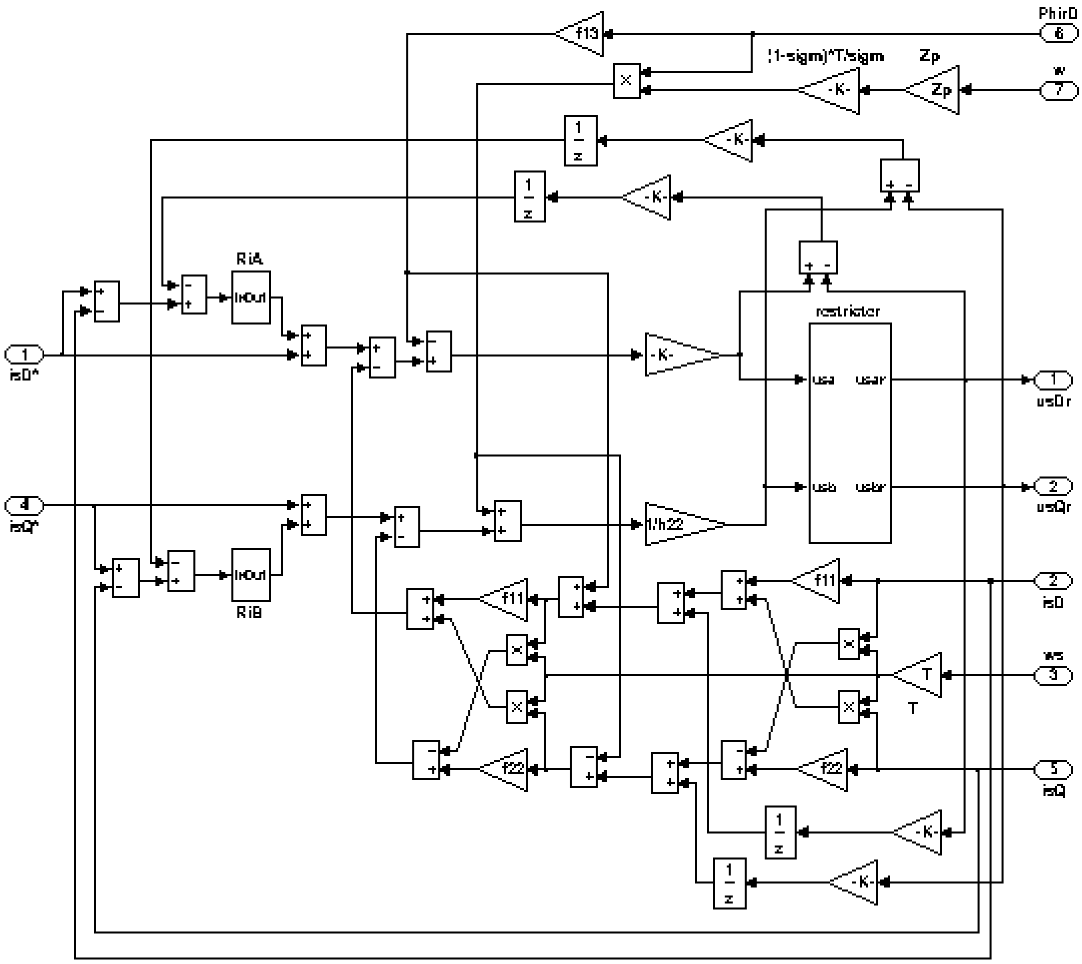
PhirD
6
(1-sigm)*T/sigm
Zp
w
7
f13
-K-
1/z
RiA
RiB
1
isD*
4
isQ*
restrictor
usa
usar
usb
usbr
1
usDr
2
usQr
1/h22
f11
f22
2
isD
ws
3
T
5
isQ

Fig 3.

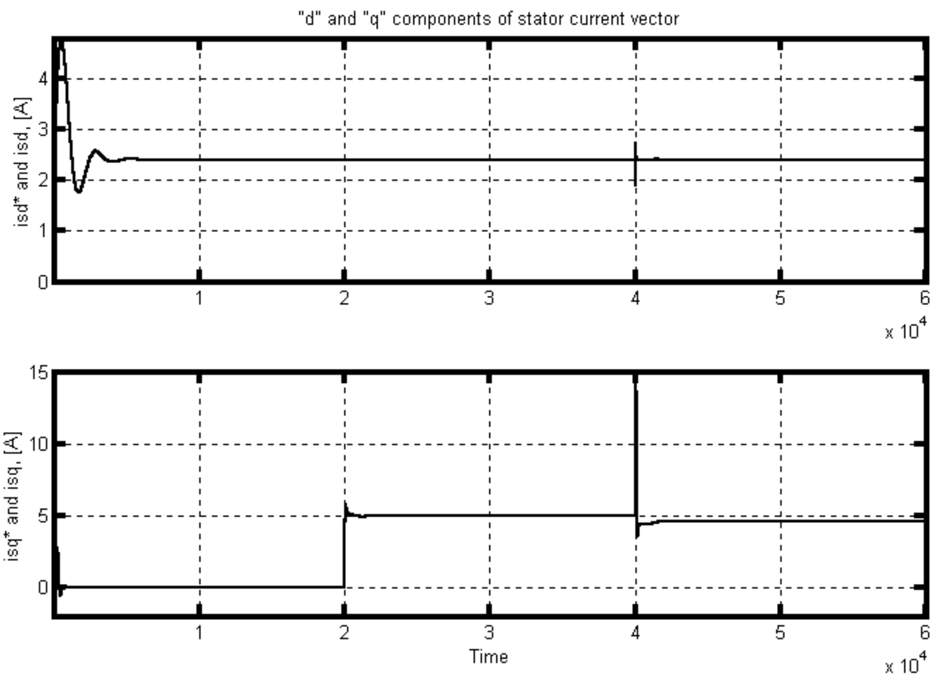
"d" and "q" components of stator current vector
isd* and isd, [A]
isq* and isq, [A]
Time
x 10^4

Fig.4.

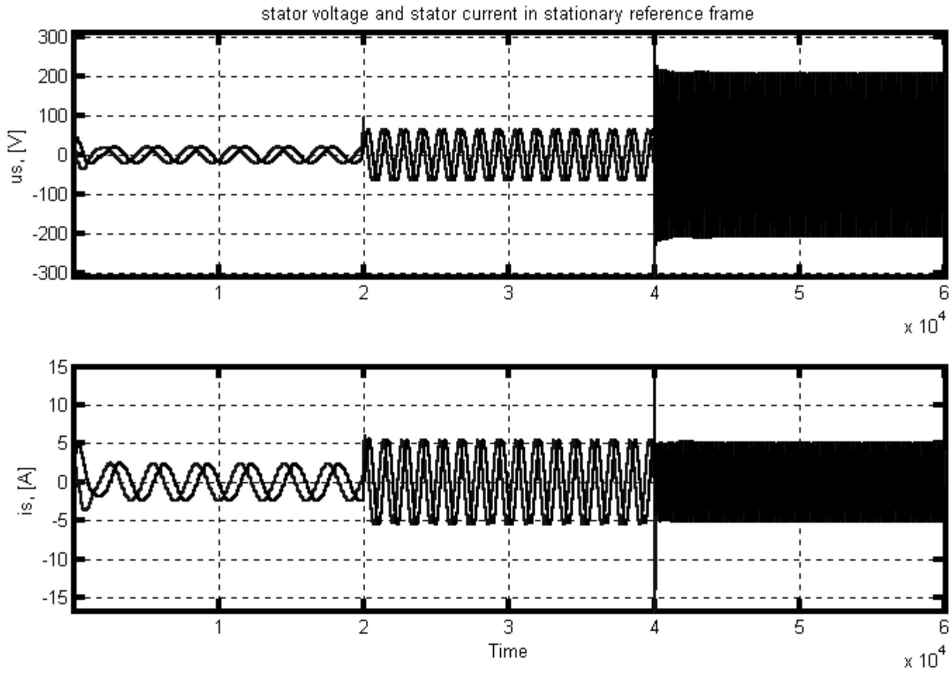

Fig. 5.

4. n the running tact the stator voltage calculates with the help of Eq. 7.

In [4] the particularities and one possible approach for limitation of the stator voltage components are described. Than the presented, up to now, steps for current regulation are illustrated in Fig. 3.The circuit is synthesis and analyzed with MATLAB/SIMULINK software. The simulations are provided for the motor next parameters:

- Tape T90L - 4 ("Elma" – Trojan)];
- Power $P_n = 1.5kW$;
- Nominal current $I_n = 3.8A$;
- Nominal phase voltage U_n=220V/50Hz;
- $J = 0.00278kgm^2$;
- z_p=2;
- n = 1400rpm;
- mM = 10.23Nm;
- $L_m = 0.291H$;
- $L_s = 0.304H$;
- $L_r = 0.3066H$;
- $T_r = 0.0726s$;
- $T_s = 0.0544s$.

The simulation is done in next conditions:

- Time 6s, 1s = 10000steps, T = 0.0001s;
- Static resistive moment mW changes steeply from 0 for 10.23Nm in the moment t = 2s;
- The determined speed of rotor's rotating n changes steeply from 100 to 1000 rpm in the moment t = 4s.

Fig. 4 shows the given and measured values of the stator currents i^*_{sd}, i_{sd} и i^*_{sq}, i_{sq}, in the coordinate system synchronized with the field. Fig. 5 presents the stator voltage an a stator current in the common coordinate system.

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