ГОДИШНИК на Минно-геоложкия университет "Св. Иван Рилски", Том 51, Св.III, Механизация, електрификация и автоматизация на мините, 2008
ANNUAL of the University of Mining and Geology "St. Ivan Rilski", Vol. 51, Part III, Mechanization, electrification and automation in mines, 2008

VECTOR CONTROL OF INDUCTION MACHINES

Ilie Borcosi[1], Alina Dincă[2], Daniela Nebunu[3], Antonie Nicolae[4]

[1] *"Constantin Brancusi" University of Tg-Jiu, Geneva Street, Nr. 2, Gorj, ilie_b@utgjiu.ro*
[2] *Constantin Brancusi University, Tg. Jiu, alina@utgjiu.ro*
[3] *Constantin Brancusi University, Tg. Jiu, dana@utgjiu.ro*
[4] *Constantin Brancusi University, Tg. Jiu, antonie.nicolae@utgjiu.ro*

ABSTRACT. The vector control which consists of maintaining the orthogonality between the flux and active current, strengthens the advantages of using the induction motors, compared to the continuous current motors.

ВЕКТОРЕН КОНТРОЛ ПРИ ИНДУКЦИОННИТЕ МАШИНИ
Илия Боркоз[1], Алина Динча[2], Даниела Небуну[3], Антони Николае[4]
[1] *Университет "Константин Бранкуш", Търгу Жиу, ул. Женева № 2, Гордж, ilie_b@utgjiu.ro*
[2] *Университет "Константин Бранкуш", Търгу Жиу, alina@utgjiu.ro*
[3] *Университет "Константин Бранкуш", Търгу Жиу, dana@utgjiu.ro*
[4] *Университет "Константин Бранкуш", Търгу Жиу, antonie.nicolae@utgjiu.ro*

Резюме: Векторният контрол, който представлява поддържане на ортогоналност между потока и реалния ток дава предимство на използването на индукционните електродвигатели в сравнение с електродвигателите на непрекъснат ток.

1. Introduction

For a long time, the induction motors were not a technical solution for adjustable control (driving), even though they are superior to the continuous current motor considering dimensions, weight, rotor ineptness, effective power, cost, reliability, exploitation expenses, etc.

Along with the recent developments in the power industrial electronics domain, with applications in variable speed driving, the adjustable driving with induction motors are used in a wide scale.

I talk about two development directions: one connected to the semiconductor devices (electronic valves) and the other one connected to their command circuits.

From the point of view of the automated speed adjustments systems with alternative current motors, a different approach must be considered, compared to the case with continuous current motors. At the continuous current motors, the flux and current in the induced circuit are independent (not coupled) and because of this, simple adjustment schemes have been designed, fully controllable and with good dynamic performances.

2. Asynchronous motor control principles

Until recently, the most used revolution adjustment method for an asynchronous motor was "Scalar Control" (or "V/Hz"). For this method, the motor works in an area in which the rotor flux is constant (volts proportionally to speed).

In case of the asynchronous motor with short-circuited rotor, the static converter must ensure the motor with the necessary active and reactive power for magnetization, because it external sources for excitation don't exist. They must be found in the statoric coiling of the asynchronous motor, both currents: excitation (reactive) and couple generator (active).

Field oriented control uses the spatial phases for modeling the AC motors, their complex structure being able to be transformed in one similar to the CC motor, characterized by the orthogonality between flux and current. As a consequence, the electromagnetic couple developed by the motor has permanently an expression of scalar product between flux and current, similar to the couple developed by the continuous current motors with separate excitation and so, maximum value. Adjustment of the couple through this method is done through decoupling the active and reactive components of the statoric currents, generators for couple and flux.

Because the expression of the electromagnetic couple may be written in different referential systems, solidary with the statoric, rotoric or magnetization flux, there are a lot of variants for adjustment schemes for each type of command.

Field control is made in a referential system which is solidary with the flux we need information about. The components of the statoric current in the corresponding referential system are similar to the excitation and to the induced current, from the CC motor case. To elaborate a corresponding command for the inverter, the statoric currents must be in report with a fixed coordinates system, solidary with the stator, through a simple coordinates' transformation, function of the system the command was elaborated into.

The implementation of the vector command with orientation after the rotoric field is the most used method.

The vector command with statoric filed orientation presents as disadvantage the necessity of measuring the statoric tensions which in the case of the inverters with pulse width modulation, very often used in practice due to their advantages, are very strongly deformed and difficult to measure.

In the specialty literature there are command modalities with magnetization flux orientation.

There are a lot of vector command modalities, no matter the type of orientation, with direct and indirect methods.

Direct methods need measuring of the flux (command with flux reaction) through direct measuring of the specific quantities with Hall sensors, measurement inductivity or measure from the statoric coiling. These methods have been abandoned because they present a series of disadvantages:

- the Hall sensores, mounted orthogonally, measure the powerfully deformed signals because of the rotor's cuts' effects and they are mechanically and thermally solicited. The method needs special construction motors;
- the measurement coils eliminate the effects of the rotor's cuts through geometric mediation, but they need special motors. Also, the measurement coils detect the flux variations, which determines a weak behavior at low frequencies;
- use of statoric coiling as measurement coils eliminate the necessity of some special motors, but there is necessary to compensate the drop of resistive tension before integration.

Indirect command methods are based on determining the amplitude and position of the flux phase from the so called flux model on the basis of the measured quantities (tensions, currents). These methods, despite their sensibility to the machine's parameters' variation and of the necessity of the speed transducer to be expensive and precise, they have a high applicability because they don't need field transducers (special motors). Another advantage is that two statoric currents and the rotation speed are necessary as reaction measured signals, the other reaction signals being calculated in real time from the "in current" model of the motor. That means the stator's parameters don't affect the model, because the statoric currents are measured.

The only important parameter of the asynchronous motor which can be modified is the time rotor constant, T_r, which increases in the high speed domain (decrease of flux), because of the desaturation of the machine and decreases with the increase of the resistance, at high temperatures.

Because of this reason, the indirect vector adjustment methods for the speed of asynchronous motors are mostly used, even though these methods need calculating the reaction quantities, development of the digital signal processors (DSP), they allow the implementation of the complex control functions specific to the AC motors, using the software instead of hardware components (which are more expensive)

In fig. 1 is shown a FOC control system. The AM is driven by the conventional voltage-source inverter. This system can be implemented using the DSC sZdspTMS320F218 and some additional hardware.

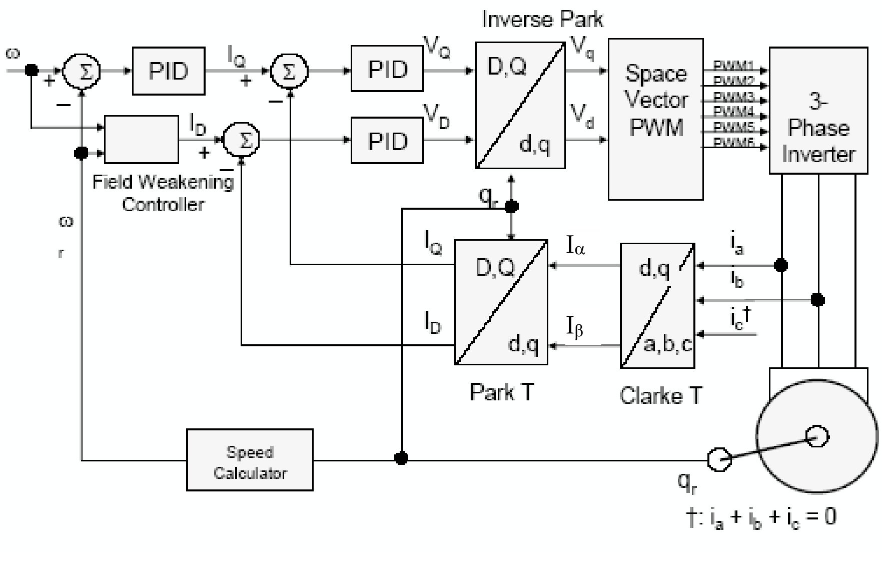

Fig. 1

The C2812 is generating six pulse width modulation (PWM) signals by means of space vector PWM technique for six power – switching devices in the inverter. Two input currents of the AM (i_a and i_b) are measured from the inverter and they are sent to the c218 via two analog – to – digital converters. The current on the third phase is not necessary to be calculated because it is obtained from the relation:

$$i_a + i_b + i_c = 0$$

The rotor position is required for variable transformation from stationary reference frame to synchronously rotating reference frame. The rotor position is obtained from the encoder. As a result of this transformation, the so called Park transformation, the q-axis current will be controlling torque while the d-axis current is forced to zero. In this case "d" means direct and "q" means Quadrature.

The Park transform has been around for 78 years. This theory requires very much mathematical calculations (matrix multiplications), which can be made in real-time with the help of DSPs.

This theory is not limited to sinusoidal distribution and can be applied to any kind of vector.

We start from the alimentation voltages' vector (V_s) of the stator (the voltage vector applied to the stator):

$$V_s = \begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix}$$

In fig. 2 is shown the change of the reference through Park transformation.

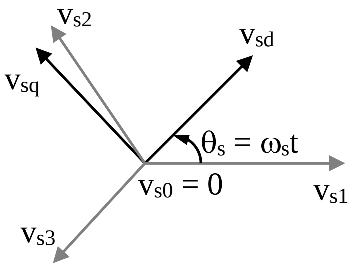

Fig. 2

This referential change transforms the V_s vector in a new vector as written below:

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} = \begin{bmatrix} cos\theta_s & -sin\theta_s & 1 \\ cos\left(\theta_s - \frac{2\pi}{3}\right) & -sin\left(\theta_s - \frac{2\pi}{3}\right) & 1 \\ cos\left(\theta_s - \frac{4\pi}{3}\right) & -sin\left(\theta_s - 4\frac{2\pi}{3}\right) & 1 \end{bmatrix} \cdot \begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix}$$

or

$$\begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix} = \left[P(\theta_s)\right] \cdot \begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} and \begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} = \left[P(\theta_s)\right]^{-1} \cdot \begin{bmatrix} v_{s1} \\ v_{s2} \\ v_{s3} \end{bmatrix}$$

For a three-phase balanced system the following relations can be written:

$$\begin{cases} \bar{v}_{s1} + \bar{v}_{s2} + \bar{v}_{s3} = 0 \\ \bar{v}_{sd} . \bar{v}_{sq} = 0 \\ \bar{v}_{sd} . \bar{v}_{s0} = 0 \\ \bar{v}_{sq} . \bar{v}_{s0} = 0 \end{cases}$$

where:

- (v_{sd}, v_{sq}, v_{s0}) are called the Park coordinates;
- v_{sd} – is direct Park component;
- v_{sq} – is squaring Park component;
- v_{s0} – is homo-polar Park component;
- v_{s0} is null for a three-phase balanced
- each pair of components is perpendicular to each other.

In specialty literature is used the normalized Park transform for which the inverted matrix is much easier to calculate and which allows building an orthogonal referential change:

$$\left[P(\theta_s)\right] = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\theta_s & -sin\theta_s & \frac{1}{\sqrt{2}} \\ cos\left(\theta_s - \frac{2\pi}{3}\right) & -sin\left(\theta_s - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ cos\left(\theta_s - \frac{4\pi}{3}\right) & -sin\left(\theta_s - 4\frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix}$$

The normalized Park can be seen as a result of the combination of the Clarke transform combined with a rotation.

Clarke transform converts balanced three-phase quantities into balanced two-phase orthogonal quantities, as in fig. 3:

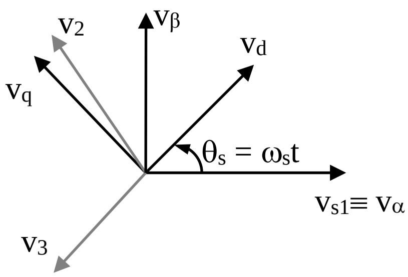

Fig. 3

Combining the Clarke and Park transforms as defined above, we move from the three-phase rotating domain to the stationary domain: we just need to control DC quantities in real-time.

To drive the power switches with new values we have to re-transform these stationary control values back into the three-phase rotating domain. This is done with a similar transform function called "Inverse Park", as in fig. 1. The control itself is done with 3 instances of a C-cellable function "PID".

3. Conclusions

The vector control offers to the asynchronous motors major advantages in report to the CC motors for the revolution adjustment systems.

Actual evolutions from the power electronics domain and the apparition of DSPs make possible the real-time control. In addition to this, Texas Instruments, world's leader for DSP production, puts at anyone's disposal for free all the necessary drivers.

4. References

1. I. Borcoşi, Olaru Onisifor, Luminiţa Popescu, Cureleanu Sorin – *"Three Phase Inverter with U/f report constant"*, Conference with international participation "Gorjeanul in mileniul III", Tg-Jiu, 18-19 November 2005.
2. I. Borcoşi, Luminiţa Popescu, Florin Grofu, Nicolae Antonie – „*Inverters with rectangular output voltage*", the XIth edition of the scientific conference of the Faculty of Engineering, with international participation, 3-4 november, 2006, Tg-Jiu.
3. Sergiu Iovanov, *Vector adjustment of the electronic control systems*, Craiova University Printing House, Craiova, 2000.
4. www.ti.com

Recommended for publication of Editorial board