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FOC CONTROL SYSTEM OF AC MACHINES

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Abstract: The vector control which consists of maintaining the orthogonally between the flux and active current, strengthens the advantages of using the induction motors, compared to the continuous current motors

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 orthogonally 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 sensors, 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;
- 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.

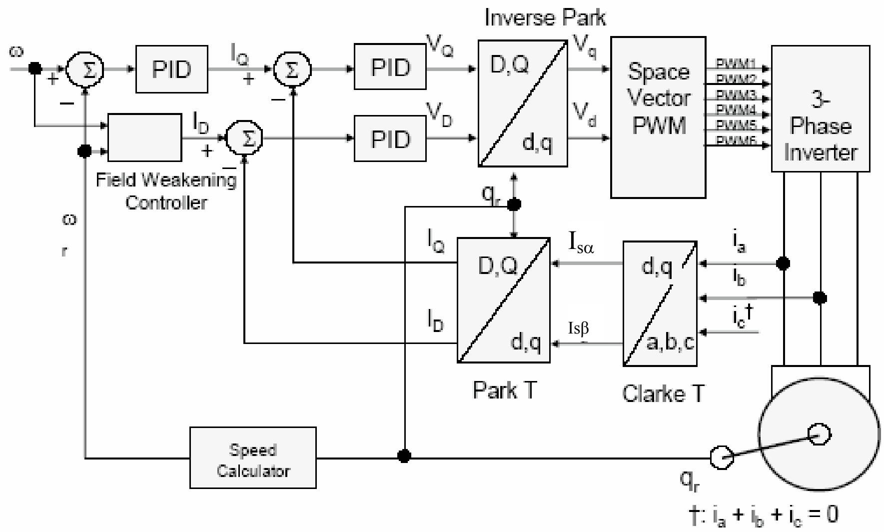

Fig. 1 Basic scheme of FOC for AC-motor

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.

The three-phase voltages, currents and fluxes of AC-motors can be analyzed in terms of complex space vectors. This current space vector depicts the three phase sinusoidal system. It still needs to be transformed into a two time invariant co-ordinate system. This transformation can be split into two steps:

· (a,b,c) =>(α,β) (the Clarke transformation) which outputs a two co-ordinate time variant system;

· (α,β) => (d,q) (the Park transformation) which outputs a two co-ordinate time invariant system.

The Clarke transformation modifies the three phase system into the (α,β) two dimension orthogonal system.

$$\begin{cases} i_{S\alpha} = i_a \\ i_{S\beta} = \dfrac{1}{\sqrt{3}} i_a + \dfrac{2}{\sqrt{3}} i_b \end{cases}$$

The Park transformation is the most important transformation in the FOC. In fact, this projection modifies a two phase orthogonal system (α,β) in the (d,q) rotating reference frame. If we consider the d axis aligned with the rotor flux, the next diagram shows, for the current vector, the relationship from the two reference frame. In fig. 2 is shown the change of the reference through Park transformation, where is the rotor flux position.

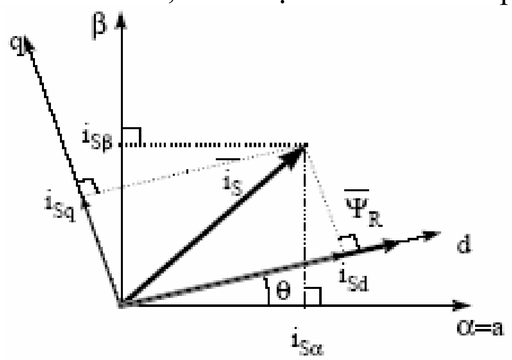

Fig. 2 Stator current space vector and its component in (α,β) and in the d,q

rotating reference frame

The flux and torque components of the current vector are determined by the following equations:

$$\begin{cases} i_{Sd} = i_{S\alpha}\cos\theta + i_{S\beta}\sin\theta \\ i_{Sq} = -i_{S\alpha}\sin\theta + i_{S\beta}\cos\theta \end{cases}$$

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.

The (d,q) =>(α,β) projection (inverse Park transformation) introduces from this voltage transformation only the equation that modifies the voltages in d,q rotating reference frame in a two phase orthogonal system:

$$\begin{cases} v_{S\alpha ref} = v_{Sdref}\cos\theta - v_{Sqref}\sin\theta \\ v_{S\beta ref} = v_{Sdref}\sin\theta + v_{Sqref}\cos\theta \end{cases}$$

The outputs of this block are the components of the reference vector that is the voltage space vector to be applied to the motor phases.

The C2812 is generating six pulse width modulation (PWM) signals by means of space vector PWM (SVPWM) technique for six power – switching devices in the inverter. Space Vector PWM supplies the AC machine with the desired phase voltages. The SVPWM method of generating the pulsed signals fits the above requirements and minimizes the harmonic contents. Note that the harmonic contents determine the copper losses of the machine which account for a major portion of the machine losses. Taking into consideration the two constraints quoted above there are eight possible combinations for the switch commands. These eight switch combinations determine eight phase voltage configurations. The diagram below depicts these combinations.

Two input currents of the AM (i_a and i_b) are measured from the inverter and they are sent to the C2812 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 current through the motor is measured with the help of two Hall transducers, mounted on two phases. The signals output from the transducers are adapted with the help of circuit in fig. 3.

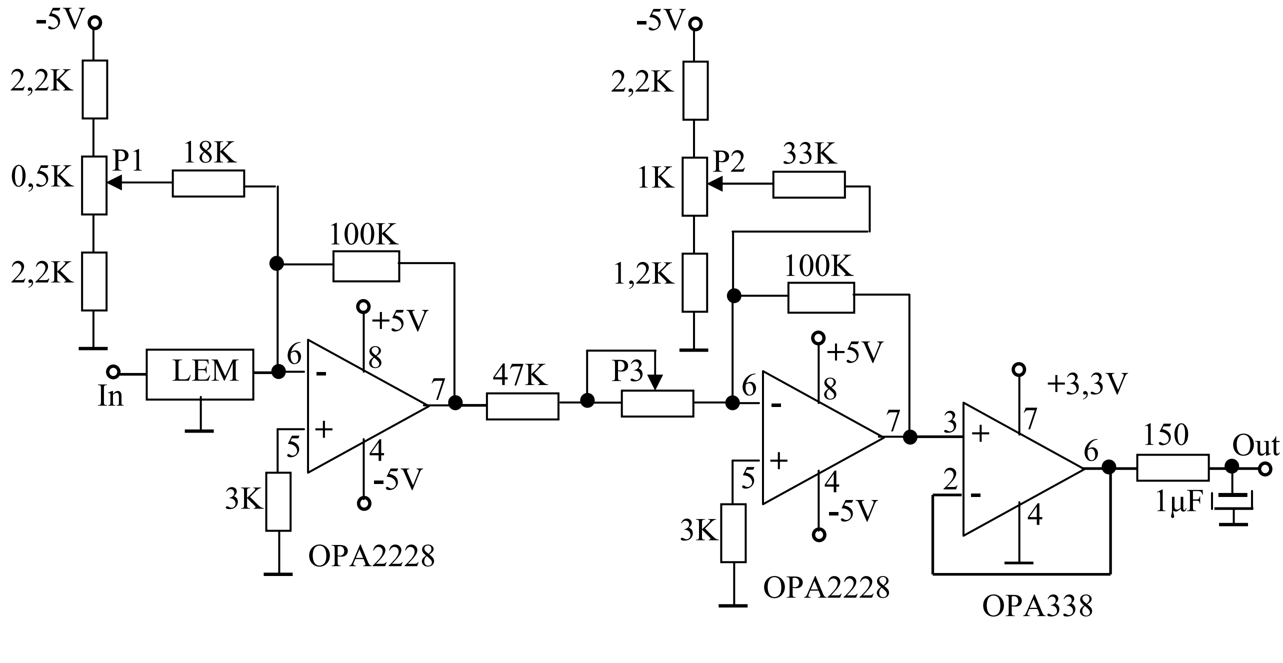

Fig. 3. The adapted circuit for the signals output from the transducers

The current transducers are LTS 6-NP type (LEM) with Hall effect and has the transfer characteristic: $V_{out} = f(I_p)$, as in fig. 4

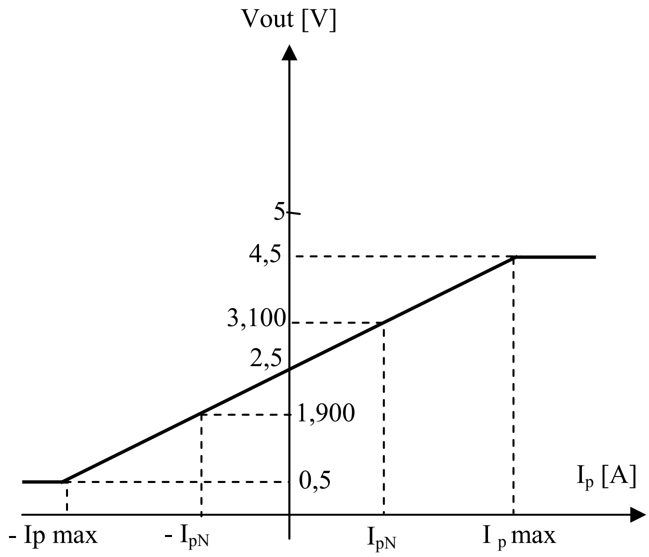

Fig. 4. The transfer characteristic for the current transducers

For certain pin connection, the effective nominal current from the primary circuit, I_{pN} =2A, and the nominal output voltage is V_{OUT} = (2,5±0,600)V.

In this application, the nominal current of the motor is 0,6A and the maximum value of the current through the motor is 1A. In this case, the maximum output voltage from the transducer is: V_{OUT} = (2,5±0,6/2)V = (2,5±0,3)V with a 300 mV variation.

The Operational Amplifiers (OA) from the adaptation circuit must have the offset voltage as low as possible, or even zero.

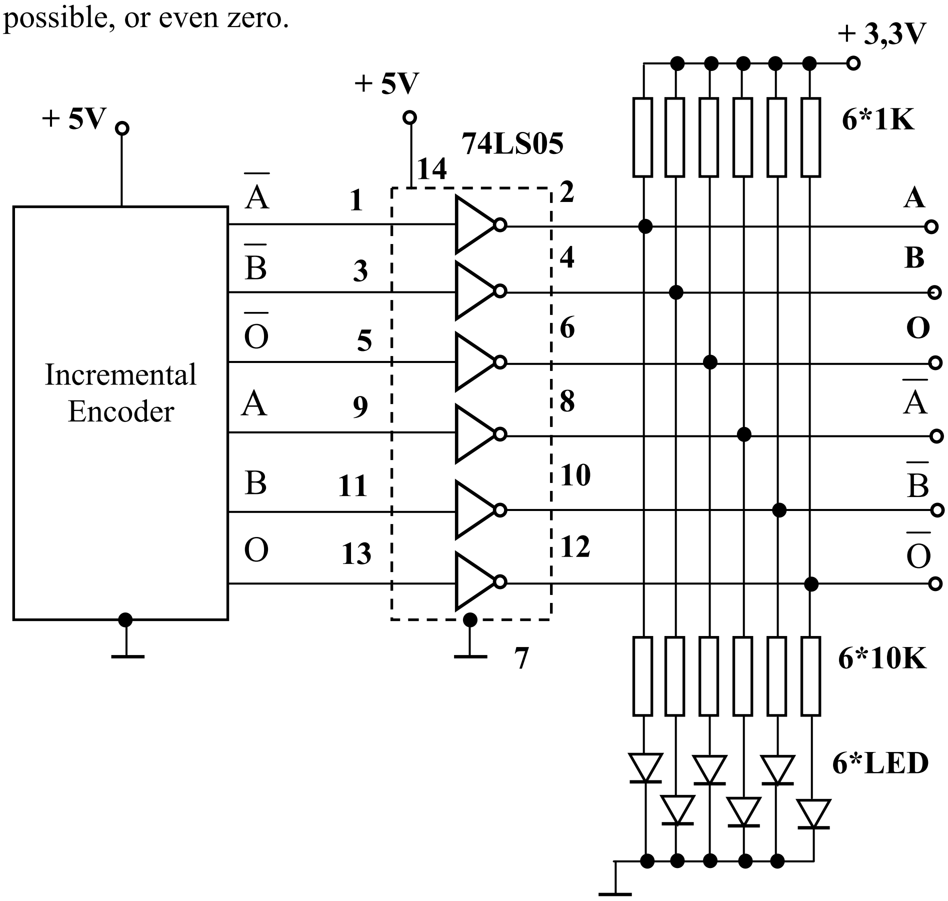

Fig. 4. The adaptation circuit, for the encoder signals.

The first OA eliminates the 2,5V level, and eventually the offset, and the second one concentrates the signal to 1,5V because the DSP allows on the analogical inputs signals of 0÷3V.

The DSP's analogical-digital converters are on 12 bits and the signal will have to be adapted to 2,5V for I_p = 1A. The signal at DSP's input will have maximum variation (1,5±1)V with 0,7V/quantum.

To adapt the output signals into PWM and the digital input ones, logical circuits, open collector type, are used. In figure 5 is presented this situation, for the encoder signals.

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

2. CONCLUSIONS

The vector control offers to the asynchronous motors major advantages in report to the CC motors for the revolution adjustment systems. Thanks to FOC it becomes possible to control, directly and separately, the torque and flux of AC machines. Field Orientated Controlled AC machines thus obtain every DC machine advantage: instantaneous control of the separate quantities allowing accurate transient and steady state management. In addition to this advantage, Field Orientated Controlled AC machines solve the mechanical commutation problems inherent with DC machines.

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.

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