SENSORLESS FOC OF 3-PHASE INDUCTION MOTORS BASED ON THE INSTASPIN SOLUTION

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SUMMARY

The induction motors are widely used in the industrial as well as residential applications thank to their simple construction and long-term working ability. During last years, the well-known field oriented control that have been applied to three-phase electrical driver systems allows engineers to construct high quality products in the motion control market. The benefits of field oriented control that can be directly realized as lower energy consumption provides higher efficiency, lower operating costs and reduces the cost of drive components. In sensorless field oriented control, the speed or position of the rotor is estimated via other parameters without using a mechanical motor rotor sensor. Recently, the Texas Instruments introduces a new solution that enables designers to identify, tune and fully control of three-phase induction motors. This solution is a firmware package named as InstaSpin that provides the designs of high performance control systems at low or medium cost for dynamic applications. In this paper, we present the use of the InstaSpin solution in a preliminary design of a three-phase inverter for speed control of an induction motor. Some simple experimental results are also provided in this paper.

Keywords: *Electrical drive system, induction motor, field oriented control, sensorless, Insta SPIN- FOC*

INTRODUCTION

In the literature, various techniques have been proposed for AC Induction Motors (ACIM) such as direct torque control (DTC) [1, 2, 3, 4], dead-beat type digital control [5], adaptive backstepping sliding mode control [6]. As a typical feature, DTC does not require an inner current controller. This leads to a simplified control configuration and allows to obtain high dynamic responses. As a disadvantage, such control schemes produce large ripples in the active and reactive power at steady state. Additionally, the deadbeat controller in [5] is designed under the assumption that the mechanical angular speed is constant during each sampling period. In every sampling cycle, their coefficients are determined under the assumption that the DFIM model is linear time-invariant, and this computation is repeated if a different value of the angular speed is measured. The main drawbacks of this approach are the high on-line computational load and the fact that the adjustment of the deadbeat controller parameters is rather ad-hoc. As a result, the performance of the system can not be guaranteed over the entire operating range of the ACIM.

Conventional control design for ACIMs is dealt with a V/Hz control approach. This method has some some natural limitations since it can not guarantee the control performance over the working range of the rotor speed. On the contrary, the Field Oriented Control (FOC) allows one to bypass these limitations by decoupling the effect of the torque and the magnetizing flux. However, this also introduces several mathematical transforms that are not easy to be implemented on analog systems. Nowadays, since the embedded systems using microcontrollers more and more utilizing in practice, these mathematical transformations can be carried out very quickly and, hence, higher dynamic performance can be achieved.

In this paper, we present an application of a breakthrough solution in ACIM control that allows to reduce development time and full

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system implementation. This solution is named as InstaSpin[7] including sensorlessInstaSPIN-FOC firmware package that provides a high performance at low/medium cost for dynamic applications [8]. Note that FOC requires precise position knowledge of rotor magnetic field to create appropriate stator magnetic field, oriented to produce maximum torque. This requires complex software algorithms in the use of the sensorlessInstaSPIN-FOC. In contrast, the sensorlessInstaSPIN-FOC provides a lower cost and no repair or replacement. The preliminary design of an inverter board and tests will also be presented in this paper.

THE FIELD ORIENTED CONTROL

The main philosophy behind the FOC is to obtain a independent control for the torque producing and magnetizing flux components similar to that of separately excited direct current (DC) motor operation. The benefit of this control technique is that the produced torque and the flux can be separately tuned via the stator current components.

ACIM model

In a dq coordinate system that is identical to the direction of the rotor flux, the mathematical model of an ACIM can be expressed as

$$
\begin{aligned}
\frac{di_{sd}}{dt} &= -\left(\frac{a+1}{T_s}+\frac{a}{T_r}\right)i_{sd} + \omega_s i_{sq} + \frac{a}{L_m T_r}\Psi_{rd} + \frac{a\omega_m}{L_m}\Psi_{rq} + \frac{a+1}{L_s}v_{sd} \\
\frac{di_{sq}}{dt} &= -\omega_s i_{sd} - \left(\frac{a+1}{T_s}+\frac{a}{T_r}\right)i_{sq} - \frac{a\omega_m}{L_m}\Psi_{rd} + \frac{a}{L_m T_r}\Psi_{rq} + \frac{a+1}{L_s}v_{sq} \\
\frac{d\Psi_{rd}}{dt} &= \frac{L_m}{T_r}i_{sd} - \frac{1}{T_r}\Psi_{rd} + (\omega_s - \omega_m)\Psi_{rq} \\
\frac{d\Psi_{rq}}{dt} &= \frac{L_m}{T_r}i_{sq} - (\omega_s - \omega_m)\Psi_{rd} - \frac{1}{T_r}\Psi_{rq}
\end{aligned}
\tag{1}
$$

where $x_r = \left(i_{sd} \quad i_{sq} \quad \Psi_{rd} \quad \Psi_{rq}\right)^T$, $v_{rs} = \left(v_s \quad v_r\right)^T$, $v_s = \left(v_{sd} \quad v_{sq}\right)^T$, $v_r = \left(v_{rd} \quad v_{rq}\right)^T$, $y_r = \left(i_{rd} \quad i_{rq}\right)^T$, $a = \frac{1-\sigma}{\sigma}$, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is total linkage coefficient, $T_s = \frac{L_s}{R_s}$ and $T_r = \frac{L_r}{R_s}$ is time constants, v_{sd}, v_{sq}, v_{rd}, v_{rq}, i_{sd}, i_{sq}, i_{rd}, i_{rq} are voltage and currents of the stator and rotor, Ψ_{sd}, Ψ_{sq} are stator flux components, L_s, L_r are stator and rotor inductances, L_m is the mutual inductance, R_s, R_r are stator and rotor resistances, $\omega_m = \omega_s - \omega_r$ is the mechanical angular velocity of the rotor, ω_s is electrical angular velocity of the stator (or grid), ω_r is electrical angular velocity of the rotor.

The classical sensorless FOC

The d component of the stator current and the electrical torque can be computed as follows

$$\Psi_{rd} = \frac{L_m}{1+sT_r}i_{sd} \tag{2}$$

$$T_e = \frac{3}{2}\frac{L_m}{L_r}p\Psi_{rd}i_{sq} \tag{3}$$

Equations (2) and (3) show that i_{sd} can be used as a control quantity for the rotor flux Ψ_{rd} and if the rotor flux Ψ_{rd} can be kept constant then i_{sq} can utilized for controlling the electrical torque T_e.

The classical FOC structure of a three-phase alternative current (AC) drive system is shown in Fig. 1. The outer loop is formed by two control loops: one for the angular speed control and the other for flux control. The field-weakening can be considered to be an option that is included to the flux control loop. The inner loop consists of the two PI current controllers, where the control loop of the current i_{sq} play the role for controlling the electrical torque T_e and the control loop of the current i_{sd}, in turn, is for controlling the rotor flux Ψ_{rd} (see equations (2) and (3)). The field angle θ_s between the rotor flux axis and the stator-fixed reference axis θ_s, the d component of the rotor flux Ψ_{rd}, and the rotor angular speed ω_r are calculated from the the stator-fixed voltages and currents. Once θ_s is estimated, the components u_{sd}, u_{sq} are transformed from the rotating field coordinates dq into the stator-fixed coordinates $\alpha\beta$ in order to obtain the stator-fixed reference voltages u_{sd}, and u_{sq}. These voltage components are used as the inputs of the well known vector space modulation block providing the required values for amplitude and phase of the three-phase voltage that need to be applied on the motor terminals [9]. Conversely, the current components i_{sd}, and i_{sq} on the rotating field coordinates dq can be transformed from the stator-fixed coordinates $\alpha\beta$ (i.e. the currents $i_{s\alpha}$ and $i_{s\beta}$).

TI'S INSTASPIN SOLUTION

The sensorlessInstaSPIN-FOC that works with synchronous and asynchronous motors provides the use of fewer motor parameters, optional start-up parameter, optional run-time parameter tracking. The observer requires no tuning, more accurate, more dynamically robust, stable at and through zero speed [7]. It also supports motor parameters identification, automatic tuning of current loops, run-time parameter compensation, start-up at and through zero speed, field weakening, better start-up under load.

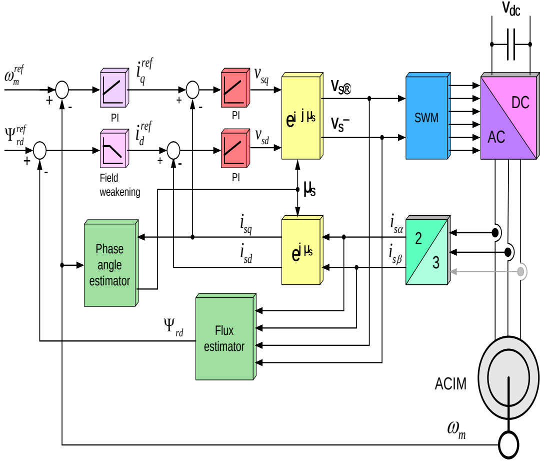


Fig 1. *The classical sensorless FOC block diagram*

On the other hand, the sensorlessInstaSPIN-FOC is also easy to use flexible software architecture, novice can call full system from ROM adjusting control gains, experts can fully customize control system calling only FAST from ROM.

The core of the sensorlessInstaSPIN-FOC is a package firmware so-called FAST. The FAST stands for Flux signal for field weakening, Angle accuracy over widest range, Speed of rotor with near zero phase lag, and Torque signal with high bandwidth and high accuracy, enabling monitoring and control of loads and flows. The InstaSpin-FOC is pre-loaded in the Read Only Memory (ROM) of the so-called TMS320F28069M microprocessors from TI as shown in Fig. 2. As alternative way, the user can also execute all FOC functions in user memory, except that the FAST estimator firmware has to be run from ROM. Employingthe benefits of the InstaSPIN-FOC the developers can save time for design and implementation of the ACIMs control systems.

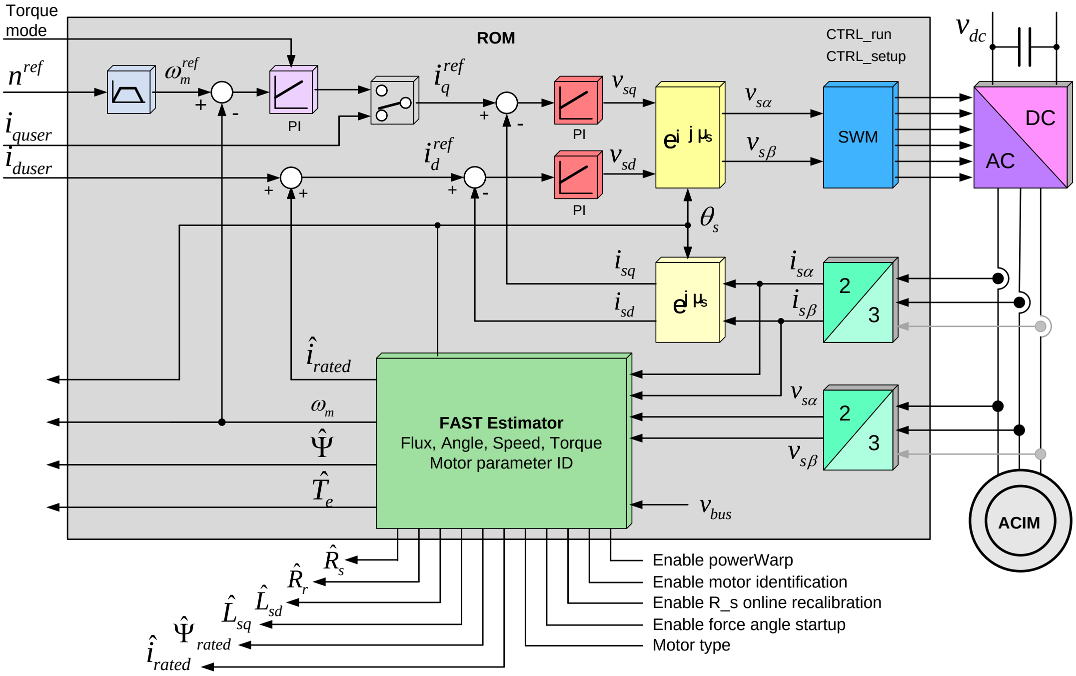


Fig 2. *The FOC block diagram in ROM*

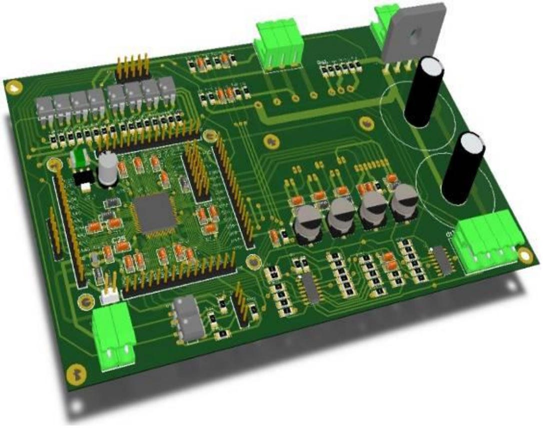
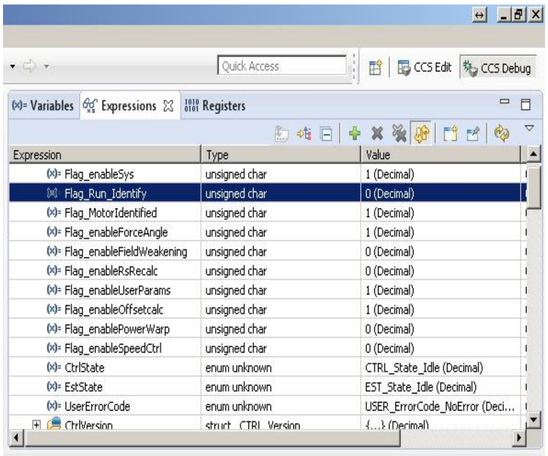


Fig. 3 *The designed inverter board*



Expression	Type	Value
Flag_enableSys	unsigned char	1 (Decimal)
Flag_Run_Identify	unsigned char	0 (Decimal)
Flag_MotorIdentified	unsigned char	1 (Decimal)
Flag_enableForceAngle	unsigned char	1 (Decimal)
Flag_enableFieldWeakening	unsigned char	0 (Decimal)
Flag_enableRsRecalc	unsigned char	0 (Decimal)
Flag_enableUserParams	unsigned char	1 (Decimal)
Flag_enableOffsetcalc	unsigned char	1 (Decimal)
Flag_enablePowerWarp	unsigned char	0 (Decimal)
Flag_enableSpeedCtrl	unsigned char	0 (Decimal)
CtrlState	enum unknown	CTRL_State_Idle (Decimal)
EstState	enum unknown	EST_State_Idle (Decimal)
UserErrorCode	enum unknown	USER_ErrorCode_NoError (Deci...
CtrlVersion	struct _CTRL_Version	{...} (Decimal)

Fig. 4 *The motor identification test*

EXPERIMENTAL RESULTS

The power module FSBS10CH60 is 600V/10A three-phase IGBT inverter with Integral Gate Drivers and Protection with low-loss, short-circuit rated Insulated-Gate Bipolar Transistors (IGBTs), separate open-emitter pins from low-side IGBTs for three-phase current sensing, single-grounded power supply. The control module uses the TMS320F28069M microprocessor as shown in Fig. 3. For the safety reason, we use this designed board for experiments in which the motor parameter identification procedure is tested with a low voltage source. The test result is shown in Fig. 4. In order to run this motor the designed board needs to be tested with a high voltage source. This will be a topic for the future works.

CONCLUSIONS

The sensorlessInstaSPIN-FOC is ideal for a variety of applications, especially for motor control. It has been reached for most developers because existing sensorless algorithms that was robust enough over real application conditions and was reducing months of development time. The InstaSPIN-

FOC technology addresses those concerns by reducing system complexity for designers of all levels while improving motor efficiency, reliability and performance at an affordable price point – which just got even lower. The design and manufacture of inverters for low-price and high-voltage level applications as well as for AC servo control systems in many areas is a promising solution in the future.

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TÓM TẮT

ĐIỀU KHIỂN TỰA THEO TỪ THÔNG ROTOR KHÔNG SỬ DỤNG CẢM BIẾN TỐC ĐỘ CHO ĐỘNG CƠ KHÔNG ĐỒNG BỘ 3 PHA DỰA TRÊN GIẢI PHÁP INSTASPIN

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Động cơ không đồng bộ 3 pha được sử dụng rộng rãi trong các ứng dụng công nghiệp và dân dụng nhờ cấu trúc đơn giản và khả năng làm việc trong thời gian dài của chúng. Trong những năm vừa qua, phương pháp điều khiển tựa theo từ thông nổi tiếng được áp dụng trong các hệ thống truyền động điện ba pha cho phép các kỹ sư có thể tạo ra được các sản phẩm có chất lượng cao trên thị trường điều khiển chuyển động. Các lợi ích của điều khiển tựa theo từ thông rotor với khả năng tiêu thụ năng lượng thấp cung cấp hiệu suất cao hơn, giảm giá thành vận hành và giá thành của các phần tử trong hệ thống truyền động. Trong điều khiển tựa theo từ thông rotor không sử dụng cảm biến tốc độ, vị trí hoặc tốc độ của rotor được ước lượng thông qua các tham số khác mà không dùng cơ cấu đo tốc độ cơ khí. Gần đây, hãng Texas Instruments đã giới thiệu một giải pháp mới cho phép các nhà thiết kế nhận dạng, điều chỉnh và điều khiển hoàn toàn các động cơ không đồng bộ. Giải pháp này là một gói phần mềm nhúng có tên là InstaSpin có khả năng đưa ra các thiết kế hệ thống điều khiển chất lượng với giá thành hạ cho các ứng dụng động học. Trong bài báo này chúng tôi trình bày việc sử dụng giải pháp InstaSpin trong thiết kế sơ bộ một biến tần cho điều khiển tốc độ động cơ không đồng bộ ba pha. Một vài kết quả thí nghiệm đơn giản cũng được đưa ra trong bài báo này.

Từ khóa: *Hệ thống truyền động điện, động cơ không đồng bộ, điều khiển tựa theo từ thông, không cảm biến, Insta SPIN-FOC*

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