Digital Signal Processing Solution for Permanent Magnet Synchronous Motor

Application Note
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TEXAS INSTRUMENTS

Abstract

This document presents a solution to control a permanent magnet synchronous motor using the TMS320C24x. This new family of DSPs enables cost-effective design of intelligent controllers for brushless motors which can fulfill enhanced operations, consisting of fewer system components, lower system cost and increased performances. The control method presented relies on the field orientated control (F.O.C.). This algorithm maintains efficiency in a wide range of speeds and takes into consideration torque changes with transient phases by controlling the flux directly from the rotor coordinates. Within this report different enhanced algorithms are presented. Among the solutions proposed are ways to suppress phase current sensors and using a sliding mode observer for speed sensorless control.

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1. Introduction

The Motor control industry is a strong aggressive sector. For each industry to remain competitive, they must not only reduce costs imposed by governments and power plant lobbies but also answer to power consumption reduction and EMI radiation reduction issues. The results of these constraining factors are the need of enhanced algorithms. DSP technology allows both a high level of performance as well as system cost reduction.

Texas Instruments launches a new DSP, the TMS320C240, specifically designed for the Digital Motor Control segment. This device combines a 16-bit fixed-point DSP core with microcontroller peripherals in a single chip solution and is part of a new generation of DSPs called the DSP controllers.

2. The DSP in motor control

2.1 Motor control trend

Traditionally motor control was designed with analog components as they are easy to design and can be implemented with relatively inexpensive components. However, there are several drawbacks with analog systems. Aging and temperature can bring about component variation causing the system to need regular adjustment, as the part count increases, the reliability of the system decreases. Analog components raise tolerance issues and upgrades are difficult, as the design is hardwired.

Digital systems offer improvements over analog designs. Drift is eliminated since most functions are performed digitally, upgrades can easily be made in software and part count is also reduced since digital systems can handle several functions on chip.

Digital Signal Processors go on further to provide high-speed, high-resolution and sensorless algorithms in order to reduce system costs. Providing a more precise control to achieve better consumption or radiation performances often means performing more calculations. The use of some 1-cycle multiplication & addition instructions included in a DSP speeds-up calculations.

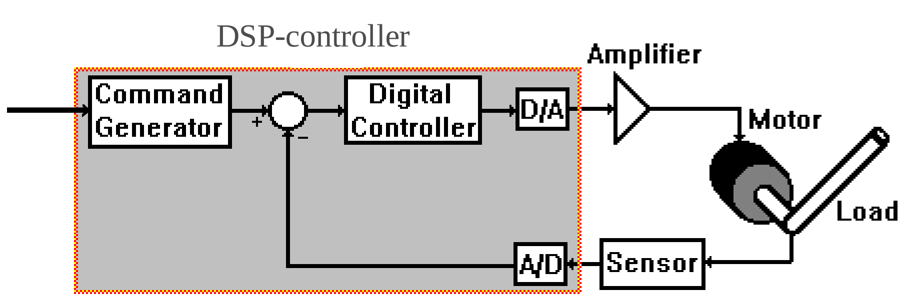
Generally fixed point DSPs are preferred for motor control for two reasons. Firstly, fixed point DSPs cost much less than the floating point DSPs. Secondly, for most applications a dynamic range of 16 bits is enough. If and when needed, the dynamic range can be increased in a fixed-point processor by doing floating-point calculations in software.

2.2 Benefits of the DSP controllers

The performances of an AC synchronous motor are strongly dependent on its control. DSP controllers enable enhanced real time algorithms as well as sensorless control. The combination of both allows a reduction in the number of components and optimizes the design of silicon to achieve a system cost reduction.

A powerful processor such as a DSP controller does the following:

- favours system cost reduction by an efficient control in all speed ranges implying right dimensioning of power device circuits
- performs high-level algorithms due to reduced torque ripple, resulting in lower vibration and longer life time
- enables a reduction of harmonics using enhanced algorithms, to meet easier requirements and to reduce filters cost
- removes speed or position sensors by the implementation of sensorless algorithms
- decreases the number of look-up tables which reduces the amount of memory required
- real-time generation of smooth near-optimal reference profiles and move trajectories, resulting in better-performing
- controls power switching inverters and generates high-resolution PWM outputs
- provides single chip control system



Control system using a DSP with additional features: the DSP controller

For advanced controls, DSPs controllers may also perform the following:

- enable control of multi-variable and complex systems using modern intelligent methods such as neural networks and fuzzy logic.
- perform adaptive control. DSPs have the speed capabilities to concurrently monitor the system and control it. A dynamic control algorithm adapts itself in real time to variations in system behaviour.
- provide diagnostic monitoring with FFT of spectrum analysis. By observing the frequency spectrum of mechanical vibrations, failure modes can be predicted in early stages.
- produce sharp-cut-off notch filters that eliminate narrow-band mechanical resonance. Notch filters remove energy that would otherwise excite resonant modes and possibly make the system unstable.

2.3 A large range of applications

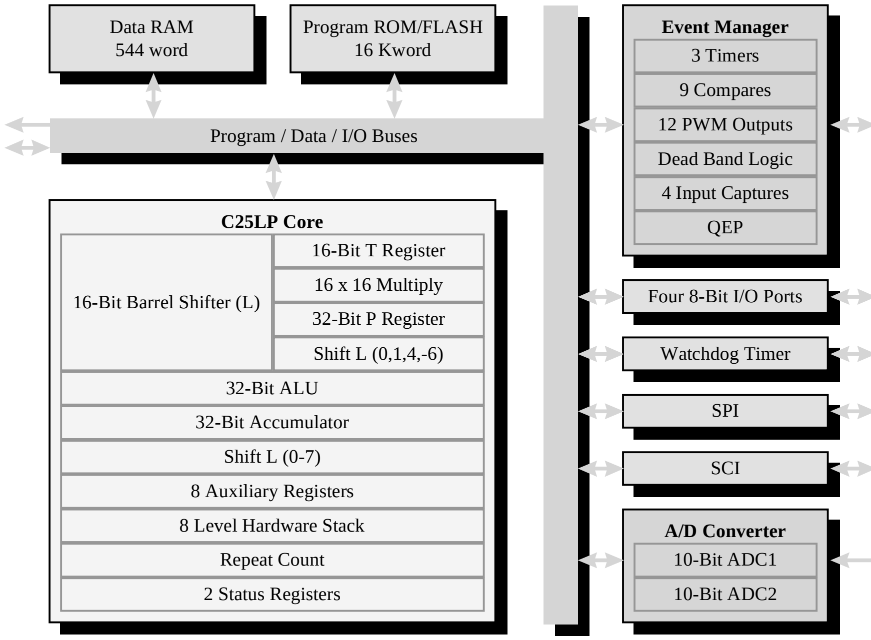
The target applications for a fixed point DSP controller having the necessary features are where the above-mentioned advantages meet the customer’s needs. Typical end equipment applications with an advanced control are:

- Appliances (washers, blowers, compressors)
- HVAC (heating, ventilation and air conditioning)
- Industrial servo drives (Motion control, Power supply inverters, Robotics)
- Automotive control (Power steerings, Anti-lock brakes, Suspension controls)

3. The TMS320C24x family

As the first DSP optimized for digital motor control, the C240 supports the power switching device commutation, command generation, control algorithm processing, data communications and system monitoring functions.

The TMS320C24x is a single chip solution, based on a 20 MIPS fixed point DSP core associated to several micro-controller peripherals such as Memory, Pulse Width Modulation (PWM) generator, Analog to Digital Converters (ADC), to provide Digital Motion and Motor Control applications.



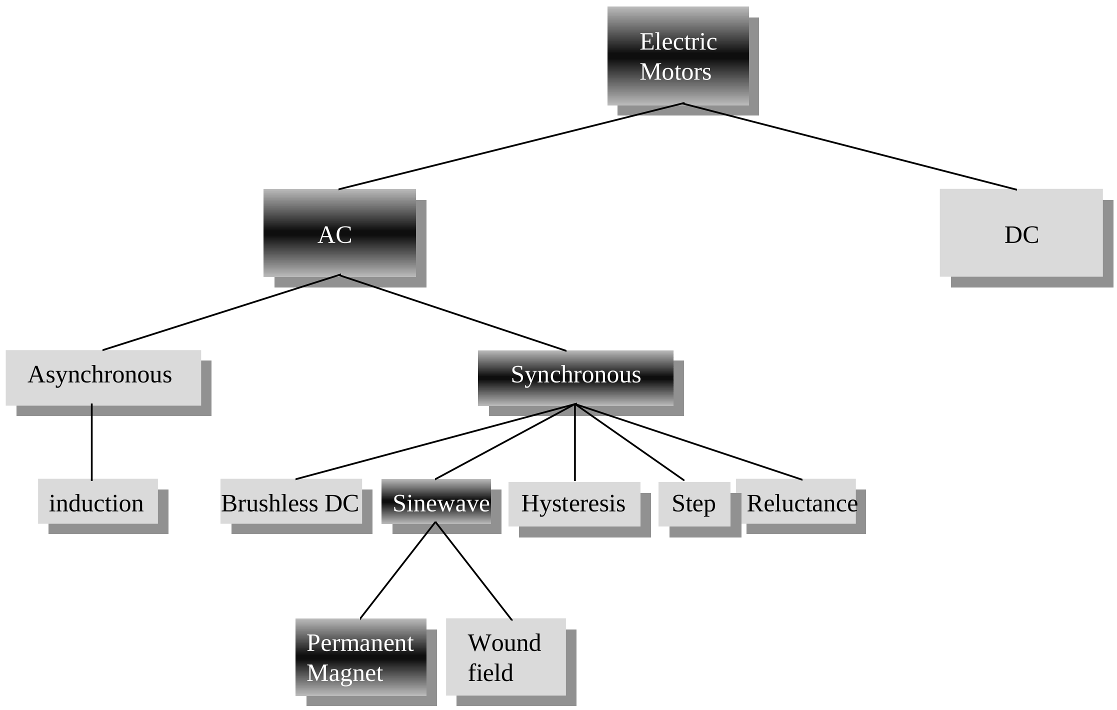
C240 Architecture

A dedicated Event Manager module generates output and acquires input signals with a minimum CPU load. Up to 4 input captures and 12 output PWM are available. Three time bases can be used to generate output signals which can be totally independent, synchronized or delayed between them. Each time base has 6 different modes and supports asymmetrical or symmetrical mode. Depending on the time base used the precision of outputs can be up to 50 ns. Three independent pairs of PWM can be complemented, using a programmable dead-band from 50 ns to 102 µs. The three pairs of PWM can support Space Vector Modulation, a method to drive a three-phase power converter.

The device includes a watchdog timer and a Real Time Interrupt (RTI) module. The watchdog module monitors software and hardware operations. A three pin Serial Communication Interface (SCI) supports communication between CPU and other asynchronous peripherals. A high-speed synchronous Serial Peripheral Interface (SPI) is also available for communication between the CPU and external peripherals or another micro-controller. Up to 28 individually programmable I/O pins are available.

4. The Synchronous motor

4.1 Electric motors



Classification of electric motors

Among all of the existing motors on the market are three ‘classical’ motors: the Direct Current with commutators (wound field) and two Alternative Current motors the synchronous and the asynchronous motors. These motors, when properly controlled, produce constant instantaneous torque (very little torque ripple) and operate from pure DC or AC sinewave supplies.

The motor studied in this application note is part of the Alternative Current supplied motors. It is synchronous as its speed may directly be determined by the stator frequency and the number of poles.

4.2 The permanent-magnet motor technology

As with most motors, the synchronous motor (SM) has two primary parts. The non-moving is called the stator and the moving, usually inside the stator, is called the rotor. SM can be built in different structures.

To enable a motor to rotate two flux are needed, one from the stator and the other one from the rotor. For this process several motor configurations are possible.

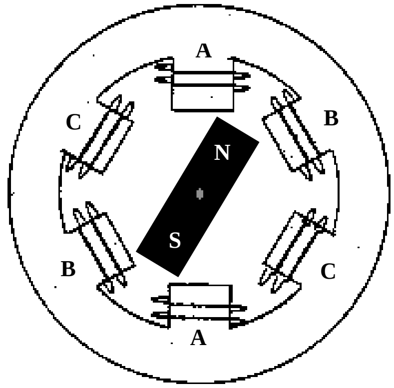
From the stator side three-phase motors are the most common. There are mainly two ways to generate a rotor flux. One uses rotor windings fed from the stator and the other is made of permanent magnets and generates a constant flux by itself.

To obtain its current supply and generate the rotor flux, a motor fitted out with rotor windings require brushes. The contacts are, in this case, made of rings and do not have any commutator segment; the lifetime of both the brushes and the motor may be similar. The drawbacks of this structure, maintenance needs and lower reliability, are then limited.

Replacing common rotor field windings and pole structure with permanent magnets put the motor into the category of brushless motors. It is possible to build brushless permanent magnet synchronous motors (PMSM) with any even number of magnet poles. Motors have been constructed with 2 to fifty or more magnet poles. A greater number of poles usually create a greater torque for the same level of current. This is true up to a certain point where due to the space needed between magnets, the torque no longer increases.

The use of magnets enables an efficient use of the radial space and replaces the rotor windings, therefore suppressing the rotor copper losses. Advanced magnet materials such as Sm_2Co_{17} or NdFeB permit a considerable reduction in motor dimensions while maintaining a very high power density. In the case of embedded systems where the space occupied is important, a PMSM is usually preferred to an AC synchronous motor with brushes.

In high-speed regions a point is reached where the supply voltage is maximum and the rotor field has to be weakened as an invert to the angular speed. In the high-speed region also called the field-weakening region, while a PMS motor needs an angle shift to demagnetise the stator windings, the SM with rotor windings maintains maximum efficiency by regulating the rotor currents and then the flux. For high-speed systems where high efficiency is required, AC synchronous motors with rotor windings may be a good compromise.



A three-phase synchronous motor
with a one permanent magnet pair pole rotor

Two configurations of permanent magnet synchronous motor drives are usually considered, depending on the back-EMF waveform: sinusoidal type and trapezoidal type. Then different control strategies (and control hardware) are implemented. In this document, a control for the sinusoidal PMS motor is described.

5. Enhanced motor control

5.1 A vector control method

A vector control is referring to the magnitude and to the phase of the control variables. Matrix and vectors are used to represent the control quantities. This method takes into consideration real mathematical equations that describe the motor itself. The space phasor theory is a method to handle the equations.

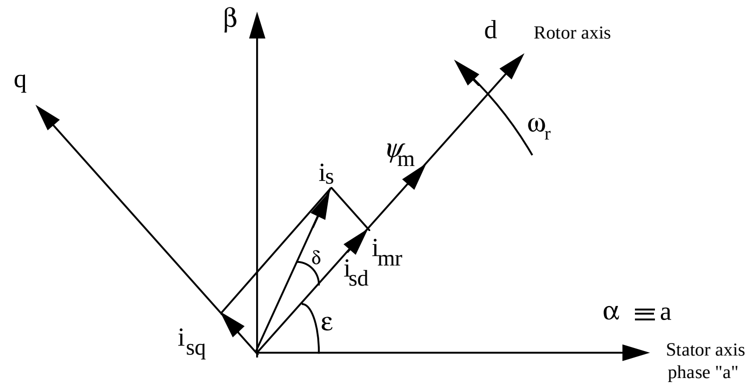
This approach needs more calculations than a standard control scheme. It can be solved by the use of a calculation unit included in a digital signal processor (DSP) and has the following advantages:

- full motor torque capability at low speed
- better dynamic behavior
- higher efficiency for each operation point in a wide speed range
- decoupled control of torque and flux
- short term overload capability
- four quadrant operation

5.2 The FOC principle

The FOC consists in controlling the components of the motor stator currents, represented by a vector in a rotating reference frame *d,q* aligned with the rotor flux. The stator current is then split into the system coordinates as follows:

$$i_s = i_{sd} + j.i_{sq}$$



Stator current and magnet flux space vectors in the d,q rotating reference frame and its relationship with the α *,* β *stationary reference frame.*

It is the preferred coordinate system used for synchronous motors via a *d,q* transformation. The control of current components requires the knowledge of the instantaneous rotor position ε , easy to measure. Two methods can be implemented to calculate i_{sd} and i_{sq} from the three phase currents i_a, i_b and i_c.

The first one consists in using an intermediate coordinate system α ,β and its phase current projections i_α and i_β, here is treated the case where $i_a + i_b + i_c = 0$.

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

i_{sd} and i_{sq} are then deduced from i_α & i_β by a rotation of the angle ε .

$$\begin{cases} i_{sd} = \cos\varepsilon . i_\alpha + \sin\varepsilon . i_\beta \\ i_{sq} = -\sin\varepsilon . i_\alpha + \cos\varepsilon . i_\beta \end{cases}$$

In the second method, i_{sd} and i_{sq} are obtained directly from i_a, i_b and i_c thanks to the general Park transformation:

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \cos\varepsilon & \cos(\varepsilon - 2\pi/3) & \cos(\varepsilon + 2\pi/3) \\ -\sin\varepsilon & -\sin(\varepsilon - 2\pi/3) & -\sin(\varepsilon + 2\pi/3) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Thanks to the coordinate transformation, the electric torque of a synchronous motor described as follows:

$$m_M = \frac{2}{3} L_0 \Im m\left[i_s \left(i_R e^{j\varepsilon} \right)^* \right]$$

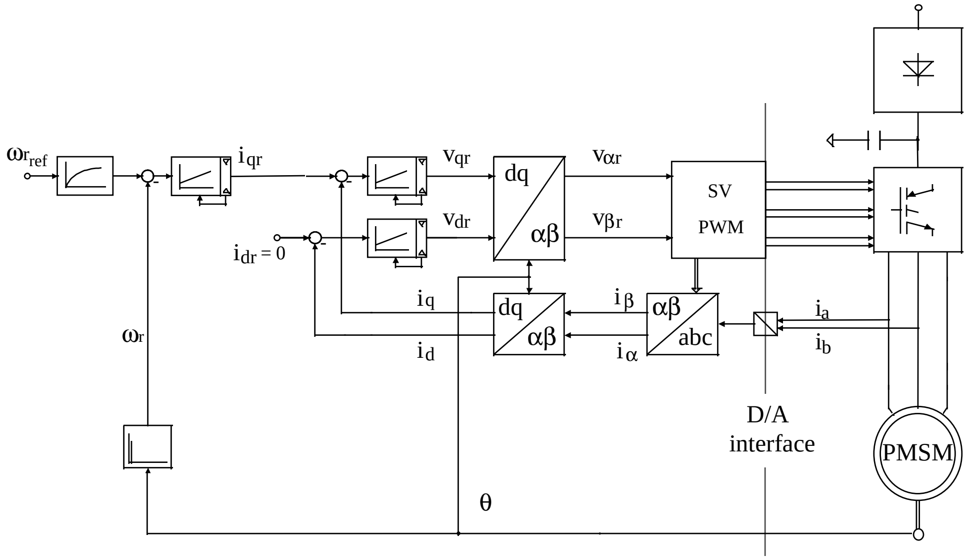
can be simplified in *d*-*q* coordinates:

$$m_M = \Phi_F \Im m\left[i_s e^{-j\varepsilon} \right] = \Phi_F i_{sq}$$

For a magnetically isotropous machine the motor torque depends only on the quadrature *q* current component (torque component).

The principle of controlling the motor is similar to the field orientated control for an induction motor except now the rotor position is the reference angle hence there is no need for a flux model. δ is the current load angle, $\delta = 0$ means no load and $\delta = \pi/2$ (or $i_{sd}=0$) is the optimal mode of operation where the motor produces the maximum torque.

The field orientated control method achieves the best dynamic behaviour, whereby the lead and disturbance behaviour can be improved with shorter control cycle times. The field orientated control is an efficient method to control a synchronous motor in adjustable speed drive applications with quickly changing load in a wide range of speeds including high speeds were field weakening is required. Its advantage is that by transforming measurable stator variables into a system based on rotor coordinates it is possible to provide a closed loop control on the current firing angle. As a result a relatively simple control method very similar to a separated exited DC motor can be applied to the synchronous motor.



Block diagram of a three-phase synchronous motor driver using a FOC structure

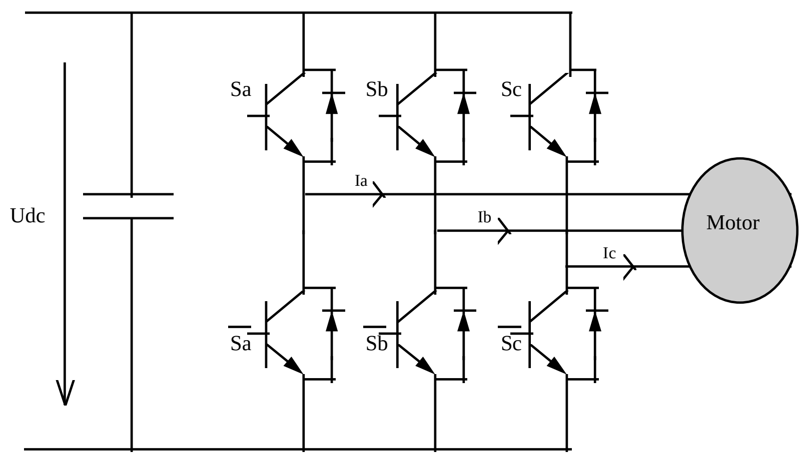
The role of the DSP in such a system is to translate the stator variables (currents and angle) into the rotor coordinates as well as to compare the values with the reference values and update the PI controllers. After the back transformation from rotor to stator coordinates the output voltage is impressed to the machine with a symmetric, an asymmetric PWM or a space vector method, whereby the pulse pattern is computed on-line by the DSP. In some systems the position is measured by an encoder, this extra cost can be avoided by implementing an algorithm as an observer model. These algorithms are complex and therefore require a fast processor, a fixed-point DSP is able to perform the above controls with short cycle times.

The FOC algorithm described in this section is related to sinusoidal or quasi-sinusoidal current waveforms and distribution of magnet flux in the stator windings. In the case of a trapezoidal back-EMF it is also possible to use a field orientated control with some addition of functions taking into account back-EMF waveform.

5.3 Space Vector Modulation

Pulse Width Modulation technique is used to generate the required voltage or current to feed the motor or phase signals. This method is increasingly used for AC drives with the condition that the harmonic current is as small as possible and the maximum output voltage is as large as possible. Generally, the PWM schemes generate the switching

position patterns by comparing three-phase sinusoidal waveforms with a triangular carrier.
In recent years, the space vector theory demonstrated some improvement for both the output crest voltage and the harmonic copper loss. The maximum output voltage based on the space vector theory is $2/\sqrt{3}$ = 1.155 times as large as the conventional sinusoidal modulation. It enables to feed the motor with a higher voltage than the easier sub-oscillation modulation method. This modulator allows to have a higher torque at high speeds, and a higher efficiency.



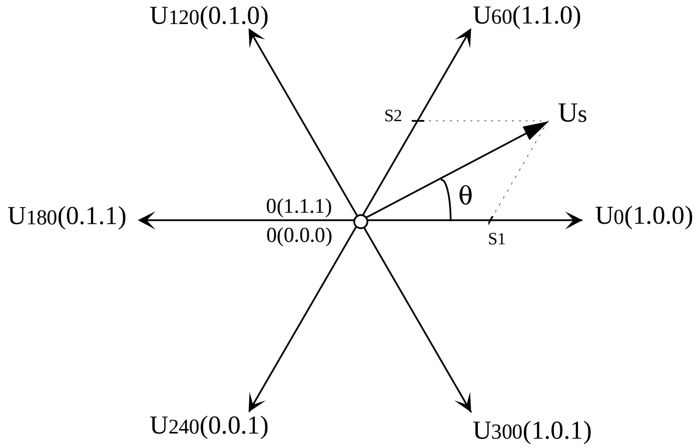
A three phase inverter fed by 3 PWM signals Sa, Sb, Sc and their respective complementary $\bar{S}a, \bar{S}b, \bar{S}c$.

For a better understanding of the space vector process and to represent the switching state of the inverter we define a switching function *Sa* for phase A as follows: *Sa = 1* when the upper transistor of phase A is on, and *Sa = 0* when the lower transistor of phase A is on. Similar definitions can be made for phase B and C.

The signals $\bar{S}a, \bar{S}b, \bar{S}c$, controlling the lower transistors, are the opposite of Sa, Sb, Sc with an addition of dead-bands.

<u>Note:</u> Dead-band is the name given to the time difference between the commutations of the upper and lower transistor of one phase. The two transistors of each phase are then never conducting at the same time. The aim of the dead-band is to protect the power devices during commutation by avoiding conduction overlap and then high transient current.

In the following graph vectors $\vec{U}_{xxx}$ are represented with their corresponding switching states between brackets, $\vec{U}_{xxx}(Sa, Sb, Sc)$.



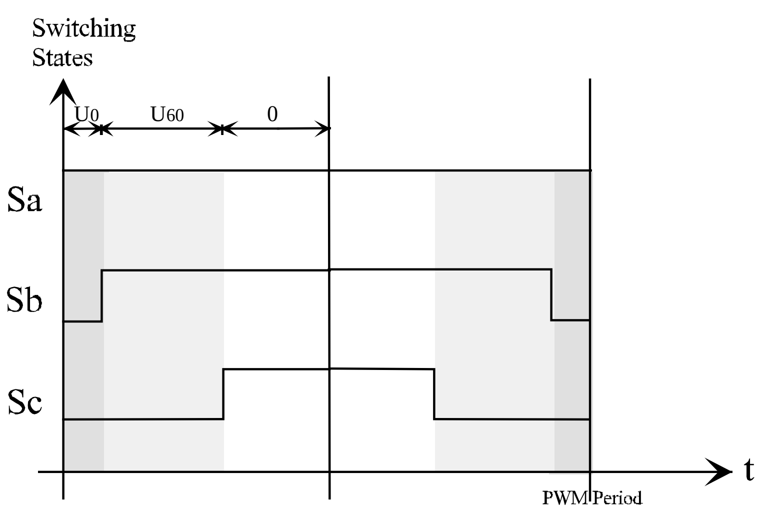
Space vector combination of $\bar{i}$

In the space vector theory the motor voltage vector is approximated by a combination of 8 switching patterns of the 6 power transistors. Us is decomposed as follows:

$$\vec{U}_s = |\vec{U}_s| e^{j\theta} = s_1\vec{U}_x + s_2\vec{U}_y$$

where $\vec{U}_x$ and $\vec{U}_x$ are two consecutive vectors. The third vector $\vec{O}(000)$ or $\vec{O}(111)$ is chosen in a way to minimize the number of switching commutations. This can be expressed with the formula:

$$T\vec{U}_s = s_1\vec{U}_x + s_2\vec{U}_y + (T - s_1 - s_2)\vec{O}$$



PWM states with $0 \le \theta \le 60\,\deg$

In the above case which is a symmetrical PWM generation, the first half period of a PWM is built with the two PWM configurations U0 and U60 characterized by the switching states (0,0,1) and (1,1,0) and the vector O: (1,1,1). The second half of the period has the same sequence but inverted related to time. This PWM scheme describes a vector U_s with an angle θ as $0 \le \theta \le 60\,\deg$.

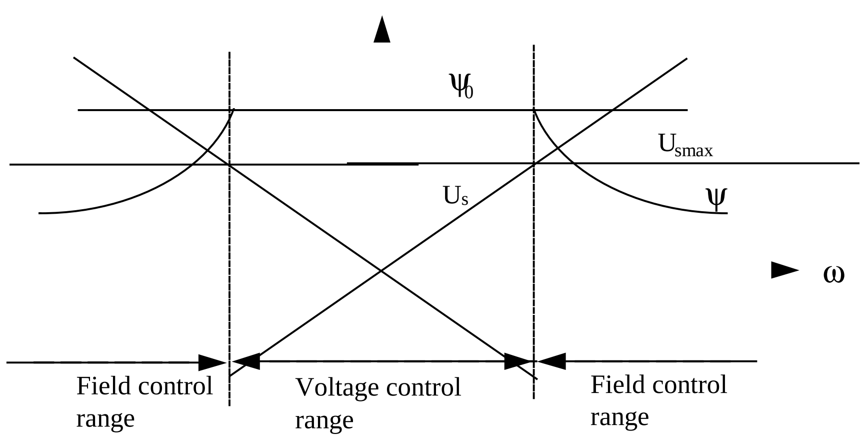
The events manager of the TMS320C240 has a built-in hardware to greatly simplify the generation of symmetric space vector PWM waveforms. The user has only to feed the corresponding registers with the above mentioned combination, the two adjacent basic vectors (in our example U0 and U60) and the rotation direction. The output control signal update is instantaneous.

5.4 Field weakening at high speeds with closed loop scheme

In order to achieve high speeds, the stator current frequency is increased. The back-EMF U_s is directly proportional to the motor flux Ψ and the angular speed ω . In normal condition the motor flux is kept constant.

$$U_s \approx j\omega.\Psi$$

Then a maximum stator speed is attained when U_s reaches the limit output voltage of the power converter. To reach a higher speed, the flux is reduced as an invert of the angular speed in order to keep the back-EMF constant and equal to its maximum.



Field and voltage characteristics for high-speed control

Practically if we consider the stator current in the d,q rotating reference frame and its relationship with the α,β stationary reference frame, below the speed where the maximum output voltage is reached, the best choice is $\delta=\pm\pi/2$ and $i_{sd}=0$. The effect of the field weakening can be achieved by advancing the current vector beyond $\delta=\pi/2$ i.e. introducing a current component in the negative d-axis. As a consequence i_{sq} and then the torque are reduced in order not to exceed the maximum output current i_{s_max}:

$$i_s = \sqrt{i_{sd}^2 + i_{sq}^2} \le i_{s\_\max}$$

Two schemes are possible to implement a field weakening operation. The simplest is the standard open loop control for the d-axis current reference. Despite the relative simplicity of realization, it has the following drawbacks:

- The reference current equation must be set in the worst condition of operation, it corresponds to the lower line voltage. It gives a low utilization of the inverter with higher voltages.
- High-speed reliability: to guarantee the correct operation of the control at high speeds it would have been necessary to reduce further the voltage capability of the inverter.
- The reference current equation depends on the motor electrical characteristics, and it’s also necessary to consider the characteristics dispersion in its determination.

A closed loop control avoids these negative effects. It consists in feeding back a proportional integral (PI) regulator with the motor d and q axis voltages applied to the motor and calculate a new reference for the magnetizing current. This diagram allows to exploit the full voltage capability of the inverter, independently from the line voltage and the motor characteristics.

5.5 Maximum DC bus voltage of the inverter control

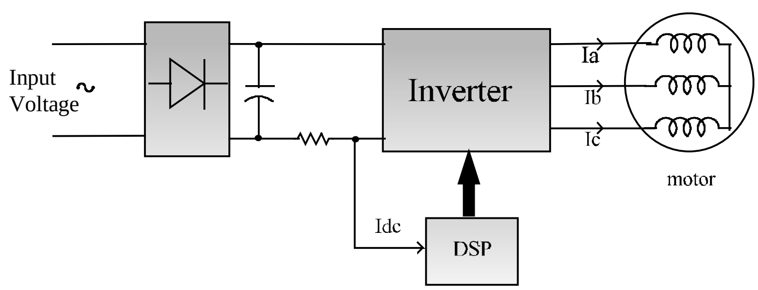
In case of a voltage supply variation the motor phase voltages have to remain constant. The DC bus voltage of the inverter is used to feedback a control loop containing a proportional regulator. The solution allows to use the motor as a brake, without the need of a ballast resistance for power dissipation on the inverter. By means of the DC voltage control it is possible to use the motor to dissipate the braking energy. In this way, the control regulates the maximum possible braking torque in order to keep the maximum allowable DC bus voltage. This algorithm may need one A/D converter input to obtain the voltage. It is also possible to calculate the voltage from the flux and the speed signals to avoid an additional voltage sensor.

6. Sensor and sensorless algorithms

6.1 Current remote measurement and calculation

In most of the inverter systems, information on the phase currents is required. The first method of obtaining those currents is to directly sense them but this requires, depending on the load schematic, at least two sensors applied directly on the motor phases. These types of sensors are usually expensive due to their sophisticated design and their need to operate in isolation.

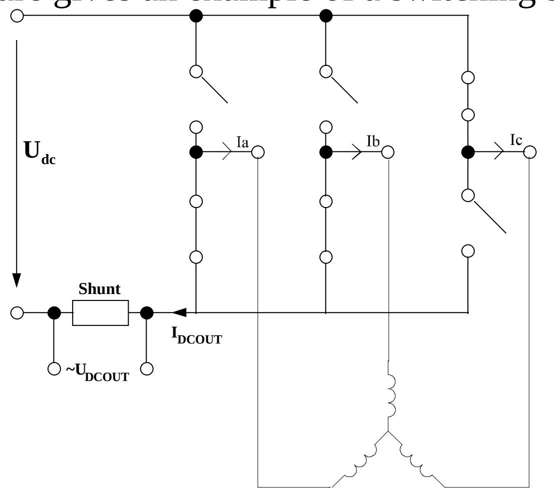
The other method is to sense only the line current, and estimate the 3 phase currents. This second method requires a simple cheap SHUNT as a sensor.



Current estimator synoptic

As we directly control the inverters switching state, it is possible to know the exact electrical route taken by the input current through the inverter to the phase. We can then directly link the phase currents to the line current. The information we measure to obtain the phase currents is a result of a real sense on the current and not the result of a simulation requiring a model of the output circuit. The measurement process is totally independent from the input and output hardware of the inverter.

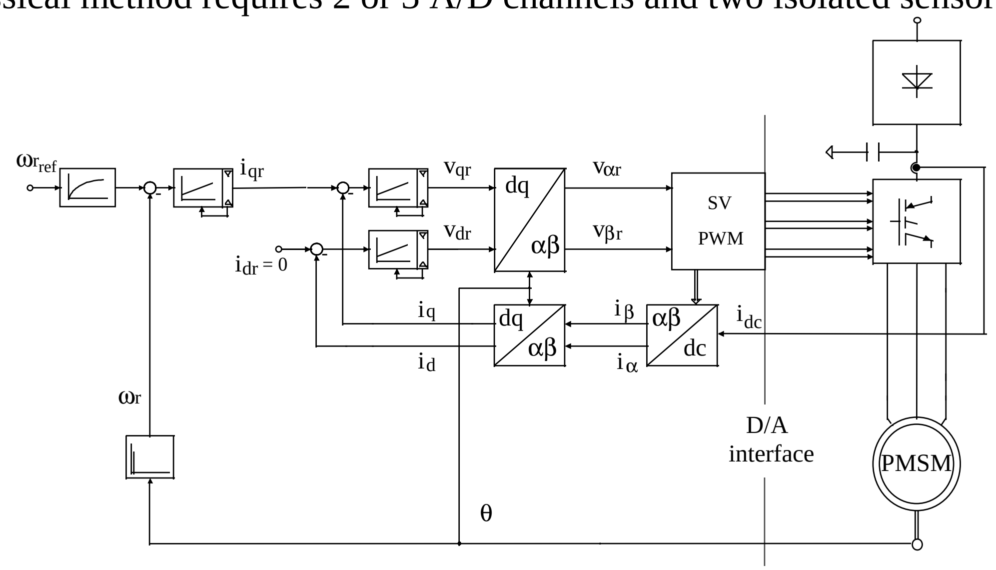
The following figure gives an example of a switching state.



Inverter supplying a net of three star windings.

Based on the above example describing the switching state (Sa, Sb, Sc) = (0,0,1), one phase current i_c can be related to the dc line current. Therefore three-phase currents can be measured, looking only at the dc line. If the Pulse Width Modulation period frequency is high enough, the phase current will only vary slightly over one or two PWM period. Hence, a measured phase current gives a reasonable approximation of the actual current.

To obtain the three-phase currents the DSP needs only one A/D channel and few calculations and a single resistor as current sensor whereas the classical method requires 2 or 3 A/D channels and two isolated sensors.



Remote current sense control scheme of a PMSM Drive

6.2 Using a speed sensor

The two most common methods of sensing to sense motor speed on the shaft, are by using an encoder of a tachogenerator. For the encoder the TMS320C240 includes a module, the quadrature encoder pulse (Q.E.P.) which perfectly handles the situation and calculates the speed and the direction of the rotation using only two digital inputs and a 16- or 32-bit internal timer register.

There are several types of tachogenerators; some build a DC voltage proportional to the motor speed, and others generate a number of pulses per rotor revolution.

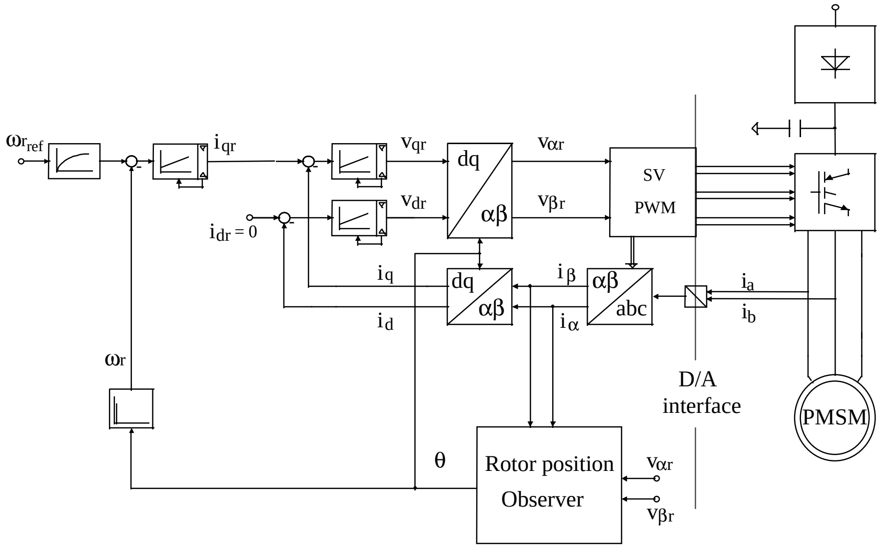
In the first case, one of the sixteen A/D converter inputs is connected to the tachogenerator output.

In the other case where hall effect sensor generates pulses, the signal enters a capture and a software driver allows the frequency measurement. The implemented software is called at fixed time intervals no longer than the minimum period of the measurable frequency. As there is only one signal, it is not possible to measure the motor speed sign. An artifice is inserted to add the sign to this speed measurement. The speed sign is memorized in a variable and only when the motor speed goes under a predetermined speed this variable is updated with the current sign. This also allows the user to execute fast speed reversing cycles in the motor.

6.3 Sensorless controlled PMSM Drive

In some applications where constraints, efficiency, reliability, mechanical and cost are all very important, it is not possible to use a speed, position or a torque sensor. In such situations, the necessary information can be derived a dynamic model called a sliding mode observer. This strategy has several advantages such as robustness and easy implementation.

Let us consider a sinusoidal permanent magnet synchronous motor that uses the vector control method whereby the state variables are transformed to a coordinate system rotating synchronous with the rotor. In rotor frame coordinates the PMSM behaves like a separately exited DC motor. The exact value of the rotor position is mandatory to control the speed, to transform the state variables, and to achieve a high efficiency. The control scheme is illustrated below.



Speed Sensorless Vector Control Scheme of a PMSM Drive

The observer is a mathematical model that requires the parameters and the structure of the controlled system. The model is driven by measurable inputs; the remaining ones are estimated. The actualisation of the model is achieved by comparing a measurable output variable with its estimation and correcting the model so that the difference between the two signals vanishes. As an example, the error of the estimated current $\hat{i}$ and the measured stator current i may be compared. The sign function (sliding mode) of $\Delta\ i$ is multiplied by a constant factor K and afterwards transferred into a continuous system using a adaptive digital filter to compensate the phase shift influence of the digital filter. The result of this procedure is the sine and cosine function of the rotor position.

The position can be determined by the study of the back-EMF, in continuous mode the equations are:

$$U = Ri + L\frac{d\hat{i}}{dt} + e$$

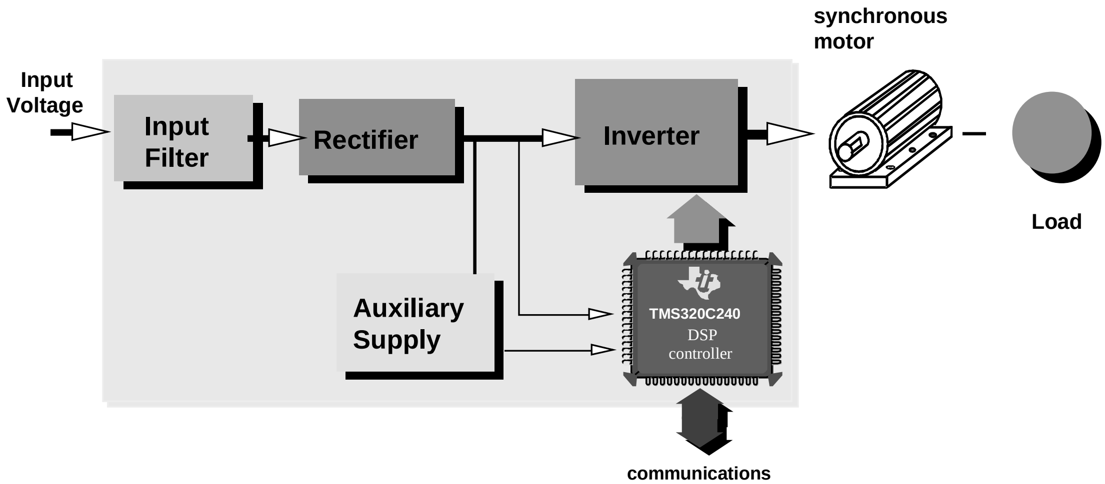
with $\quad \frac{d\hat{i}}{dt} = \frac{1}{L}\left(U - r_s i - z\right) \quad$ and $\quad z = K\left[sign\left(\hat{i} - i\right)\right]$

e is the back-EMF and z the sliding mode estimated back-EMF.

7. An example studied

Below is an example of the implementation and realization of a PMS motor controlled in speed and connected to an alternative voltage supplier. Few results are given.

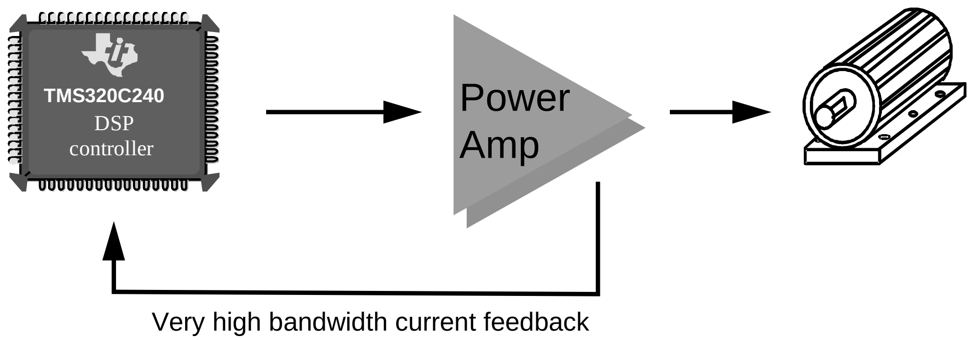
7.1 Power electronics



Three-phase PMS motor driver

The input filter block includes the hardware protections, EMI filter and an optional power factor correction (PFC). The PFC may be active or passive, in the case of active it can be entirely handled by the DSP. To achieve a continuous voltage out of the alternative input signal, a single-phase input bridge with tank capacitor is needed represented as the rectifier block. To generate the phase voltages with variable amplitude and frequency a 3-phase inverter is used, based on an IGBT technology. The system is controlled by the DSP TMS320C240. The inputs are a tachogenerator to measure the speed, a resistor divider to sense the voltage bus (V_{BUS}), a resistor sensor on the line (I_{BUS}) to estimate the phase currents, and a temperature sensor. The controller uses a serial link to communicate. The auxiliary supply feeds the inverter driver and the logic circuitry.

7.2 The control strategy



System schematic

The above figure presents a complete system structure of a sensorless controlled PMSM.

The control uses a space-vector PWM modulator. The speed, flux and current controllers are all implemented using a standard PI regulator block, with double precision for integral part. The coordinate transformation block is standard and uses the rotor angle to transform the stator phase currents values in the d-q axis frame. To reduce the number of sensors, the phase currents are calculated from the DC bus current with the current estimator block and uses one shunt and no galvanic or optical decoupling unit because the DSP controller is related already to power ground. No speed sensor is used, and the position sensor is replaced by a sliding mode observer that requires a model of the motor but does not need a close load behavior definition.

7.3 Software implementation

The proposed control scheme is implemented on the TMS320C240. All the control routines are implemented using assembler language with fixed precision numerical representation.

The control algorithm is synchronised by the DSP internal Timer that generates interrupts.

Phase currents remote measurements need sampling of the inverter DC current during the some PWM periods. The sampling time varies as a function of the actual PWM pattern. This is obtained driving the A/D conversion through another interrupt (compare register interrupt) and the result is received through an end-of-conversion interrupt.

7.4 Few results

The calculation time of the whole control algorithm is less than 40 µs. The inverter switching frequency is 16 kHz. The speed control takes 2 µs and is calculated every 28 cycles, then 1.75 ms. Phase currents remote measurements need to sample the inverter DC current during the PWM period at instants that vary as a function of the actual PWM pattern. The memory space needed is less than 1.2K word of ROM, 100 word of RAM and uses 70% (14 MIPS) of the DSP Controller performance.

The achieved electronic efficiency is higher than 95% and the total efficiency > 90%.

The speed error was under worst-case conditions less than 1.5% and the response time to a speed step from 0 to base-speed is less than 5s.

8. Conclusion

This paper presents a new controller architecture the DSP-Controller and its single chip solutions for the control of a PMS motor. The DSP-Controller TMS320C240 combines the performance of a DSP architecture with the optimized peripherals of a Microcontroller. With the DSP-Controller an intelligent control approach is possible to reduce the overall system costs and to improve the reliability of the drive system.

9. References

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