

Brushless DC Motor speed controller using DSP Processor approach

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ABSTRACT: This paper presents digital speed control of permanent magnet brushless dc motor using TMS320LF2407 DSP controller. The DSP controller used here has the special features for digital motor control. Control algorithms used for the speed control has been implemented by c language programming in TMS320LF2407 DSP controller. According to the input command, feedback and the control algorithm, the PWM pulses for each phase is generated by the DSP and is given to the MOSFET driver. The output of the driver is 6 independent PWM pulses that have to be given to the corresponding gates of the six MOSFETs power switches used in the three-phase bridge inverter whose output is given to the stator of the Brushless DC Motor. The complete system model is simulated in MATLAB/ Simulink environment. Hardware implementation for the speed control has been achieved by programming in the DSP controller TMS320LF2407.

KEYWORDS: Brushless DC Motor, DSP controller, Pulse Width Modulation(PWM), TMS320LF2407.

I. INTRODUCTION

Recent developments in power electronics, fast digital signal processors (DSPs) and modern control technologies have significantly influenced the wide spread use of permanent magnet brushless (BLDC) motor[9] drives in order to meet the competitive worldwide market demands of manufactured goods, devices, products and processors. Large, medium, small as well as micro BLDC motors are extensively sought for applications in all sorts of motion control apparatus and systems. The availability of smart power electronics devices and their optimal topologies has accelerated unprecedented growth of cost effective and reliable inverter and converter systems. Software controlled online implementation of sophisticated robust controllers has advanced the art of digital control of BLDC motor drives. In electric traction, like in other applications, a wide range in speed and torque

control for the electric motor is desired. The DC machine fulfills these requirements but these machines needs periodic maintenance. The AC machines like induction motors and brushless DC motor [1] does not have brushes, and their rotors are robust because commutator and or rings do not exist. That means very low maintenance. This also increases the power to weight ratio and efficiency. For induction motors flux control has been developed, which offers a high dynamic performance for electric traction application however this control type is complex and ophisticated. The development of BLDC has permitted an important simplification in the hardware for electric traction control.

Moreover designers have recognized the opportunity to redesign existing systems to use advanced algorithms. For improved efficiency and torque performance, brushless DC (BLDC) motors require a phase advance circuit. Because of the problem of controlled phase advance in BLDC motor we need digital control methodology instead of conventional analog control for the speed control of PMBLDCM. By applying direct digital control it will substantially increase the effective speed range and facilitates a constant power profile. Here the DSP controller is designed to meet the needs of control-based applications of Brushless DC Motor. BLDC motors are becoming popular in Aerospace applications due to better speed v/s torque characteristics , higher efficiency, high power to frame size, silent operation and reliability [10],[11].

DSPs enable: Design of robust controllers for a new generation of full variable-speed control of brushless motor types that have lower manufacturing cost and higher reliability, Saving up to 25% of the energy used by fixed-speed controllers, Reduced manufacturing and maintenance costs ,More efficient and quieter operation due to less generation of torque ripple, resulting in less loss of power, lower vibration, and longer life. The TMS320LF2407 DSP controllers are designed to meet the needs of control-based applications. [12],[13].

In this paper modeling of PMBLDCM which is achieved by the classical modeling equations is explained in detail. closed loop speed control is implemented by using a digital PI controller in the simulation. And in the hardware part the control algorithm is implemented in DSP controller TMS320LF2407. The

commutation scheme used here which is theoretically a compromise between six-step trapezoidal commutation and the sinusoidal commutation is also presented in this paper. This commutation scheme has considerably lesser torque ripple in comparison to the existing trapezoidal commutation also it addresses the inherent disadvantage of higher switching losses associated with sinusoidal commutation. The simulation was carried out in MATLAB/Simulink environment.

II. SIMULATION MODEL OF CLOSED LOOP SPEED CONTROL OF PMBLDC MOTOR

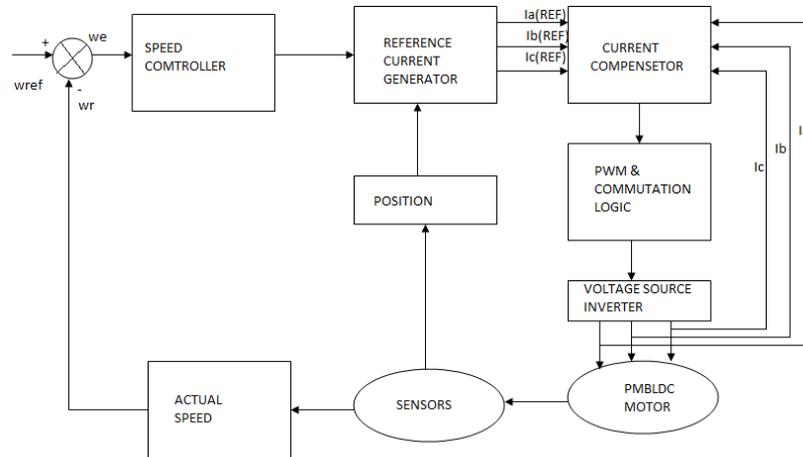


Fig .1 Block Diagram for the closed loop speed control of PMBLDC motor

The block diagram for the speed control of Brushless motor is as shown in fig.1. It consists of speed controller, reference current generator, current compensator, PWM and commutation logic circuit, Voltage Source Inverter(VSI),and PMBLDCM and sensors. The proposed model has a flexible structure and enables users to change motor parameters easily unlike the state space models of BLDC Motor which are limited in their flexibility. Each subsystem determines the parameters of the BLDC motor [3]. The Complete Simulink Model is as shown in Fig 2. Different subsystems of the simulink model are discussed in detail.

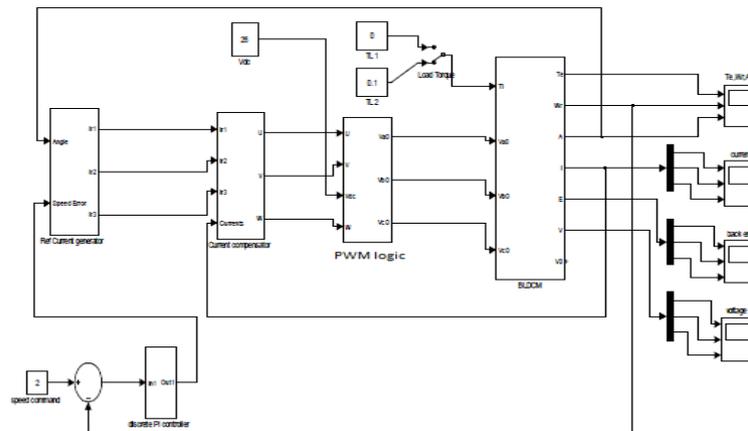


Fig.2 Simulink model

2.1 Modeling of BLDC Motor

Modeling of the BLDC motor is done using classical modeling equations and hence the motor model is highly flexible unlike the state space models. These equations are described based on the dynamic equivalent circuit of BLDC Motor which is shown in fig.3.

The BLDC Motor has three stator windings and a permanent magnet rotor. For modeling and simulation purpose assumptions made are the common “Y” connection of stator windings, three phase balanced system and uniform air gap. The mutual inductance between the stator phase windings are negligible when compared to the self inductance and so neglected in designing the model[3]

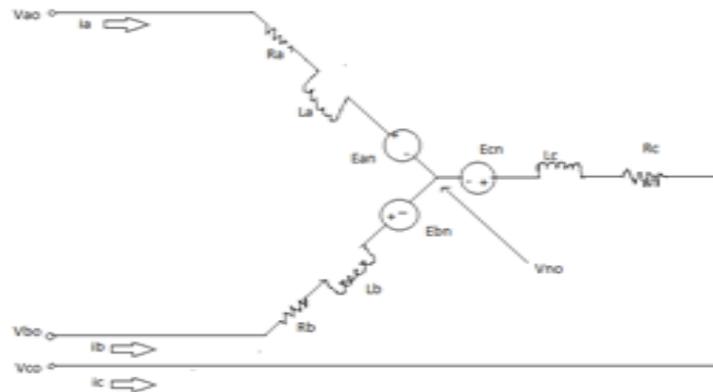


Fig .3 The equivalent circuit of BLDCM

Classical Modeling equations involves,

$$V_{n0} = \frac{1}{3}([V_{a0} + V_{b0} + V_{c0}] - [E_{an} + E_{bn} + E_{cn}]) \quad (1)$$

Where,

V_{n0} - Neutral point node voltage

V_{a0} , V_{b0} , V_{c0} -Stator phase voltages.

E_{an} , E_{bn} , E_{cn} -back emf's in the respective phases.

For this model , considering symmetrical distribution of windings,

$R_a = R_b = R_c = R$ - Stator resistance per phase,

$L_a = L_b = L_c = L$ -Inductance per phase,

Stator phase voltages with respect to neutral point are given by,

$$V_{an} = V_{a0} - V_{n0} \quad (2)$$

$$V_{bn} = V_{b0} - V_{n0} \quad (3)$$

$$V_{cn} = V_{c0} - V_{n0} \quad (4)$$

Where,

V_{an} , V_{bn} , V_{cn} - Stator phase voltages with respect to neutral point.

Also

$$V_{an} = i_a R_a + L \frac{di_a}{dt} + E_{an} \quad (5)$$

$$V_{bn} = i_b R_b + L \frac{di_b}{dt} + E_{bn} \quad (6)$$

$$V_{cn} = i_c R_c + L \frac{di_c}{dt} + E_{cn} \quad (7)$$

Where,

i_a , i_b , i_c - Stator phase currents.

Back EMFs will be of the form

$$E_{an} = \omega_r k_b \sin(\theta) \quad (8)$$

$$E_{bn} = \omega_r k_b \sin((\theta) - (2 * \pi) / 3)) \quad (9)$$

$$E_{cn} = \omega_r k_b \sin((\theta) - (4 * \pi) / 3)) \quad (10)$$

From which the stator Phase currents are estimated as,

$$i_a = [V_{an} - E_{an} - i_a R_a] * [1 / L_s] \quad (11)$$

$$i_b = [V_{bn} - E_{bn} - i_b R_b] * [1 / L_s] \quad (12)$$

$$i_c = [V_{cn} - E_{cn} - i_c R_c] * [1 / L_s] \quad (13)$$

Total electrical torque developed,

$$T_e = [E_{an} * i_a + E_{bn} * i_b + E_{cn} * i_c] / \omega_r \quad (14)$$

From the dynamic model equation of motion of the motor,

$$[T_e - T_l - \omega_r * B] * (p / 2j) / 1 / s = \omega_r \quad (15)$$

Where,

j - Moment of inertia- Friction constant

Again we know,

$$d(\theta) / dt = \omega_r \quad (16)$$

From which rotor displacement can be found out as,

$$\theta = (1/s) * \omega_r \quad (17)$$

The complete system model for the BLDC Motor is shown in the fig.4 where each subsystem in it is created according to the classical modeling equations discussed above.

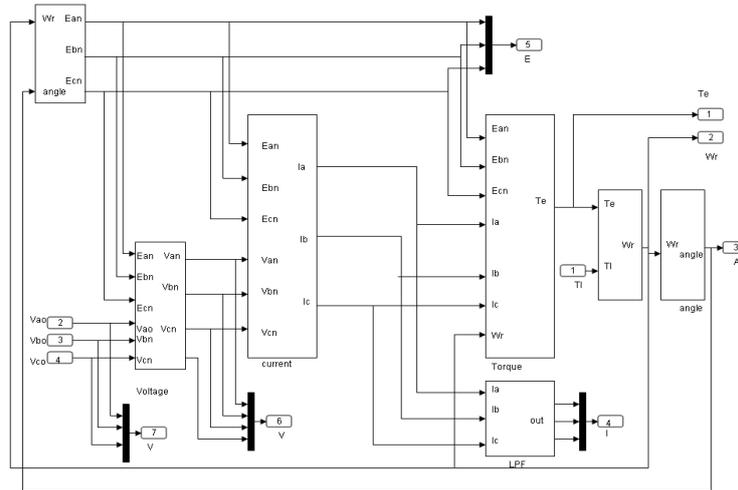


Fig.4 BLDCM sub block

2.2 Digital PI controller

The input to the PI controller is derived by comparing rotor speed $wr(n)$ with reference speed $wr(n)$ *using a summer and the resulting error is estimated at the n th sampling instant as :

$$we(n) = wr(n) * -wr(n.) \quad (18)$$

Fig.5 represents the simulink model for a digital PI controller

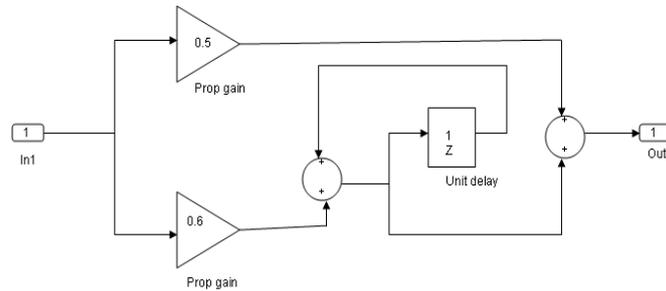


Fig 5.Digital PI controller

2.3 Reference current generator

The magnitude of the three phase current (I^*) is determined by using reference torque (T^*) and the back emf constant (K_b) as $I^* = T^* \cdot K_b$. Depending on the rotor position, the reference current generator block generates three-phase reference currents (ia^* , ib^* , ic^*). Three position signals from the hall sensors and the speed error signals are multiplied in order to generate the reference current generator. Fig.6 represents the simulink model for reference current generator.

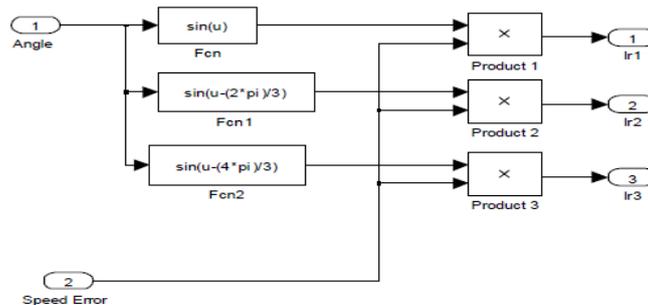


Fig.6 Reference current generator

2.4 Current compensator

Three reference current outputs from the reference current generator and the actual currents from the motor are compared each other and the resulting outputs are given to the PWM sub block. Current Compensator subsystem is shown in fig.3.5

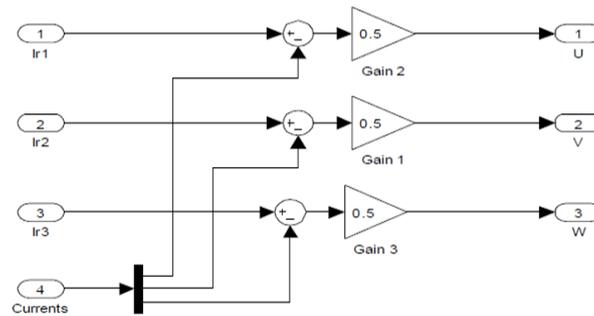


Fig.7 Current compensator

2.5 Commutation scheme

Brushless DC Motor can be classified as of sinusoidal or trapezoidal type according to the rotational voltage(back emf) induced. Trapezoidal excitation has lower switching loss while sinusoidal excitation has lower copper loss. The relatively low switching loss for trapezoidal excitation is due to the fact that only one phase is chopping at a frequency at a time, while in sinusoidal type all the three phases are chopping at same time[7][8].

A comparison between Trapezoidal and sinusoidal commutation can be done as follows. In trapezoidal commutation there will be lesser switching and implementation is simpler. Also there will be higher torque ripple and poor harmonic performance. But in sinusoidal commutation harmonic performance is better and theoretically no torque ripple. Also switching losses is higher and implementation is complex in sinusoidal commutation. Here a novel commutation scheme which will reduce the disadvantages of both trapezoidal and sinusoidal commutation has been implemented.

This commutation scheme utilizes the six non-zero switching vectors of the 2-level inverter to synthesize the reference vector at any instant. This scheme implements near sinusoid commutation without use of high resolution encoders and the number of switching is also reduced. So there will be considerable reduction in switching loss resulting in lower switching losses.

There are eight available switching states for a 2-level inverter of which six are non-zero switching vectors and two are zero vectors. The vectors shown in Fig.2 are switched to synthesize the reference vector[6]. The six active non-zero vectors are located at the vertices of a hexagon. The hexagon is divided into six regions marked 1 – 6.

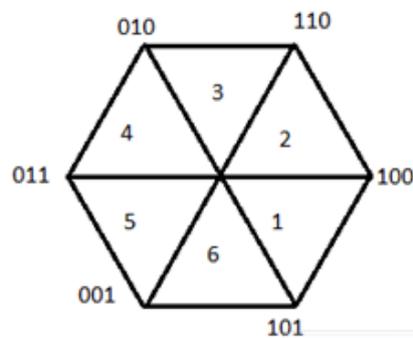


Fig.8 switching vectors used in the commutation scheme

It may be noted that the vectors located at the ends of the region are 1 0 0 and 1 1 0 in the region marked as 2 in fig.8 Here for the three phases of the inverter circuit phase A is clamped to 1 and Phase C is clamped to zero. The only phase which switches is the Phase B. So, from the rotor position if it is possible to identify from among the six regions of the 2 level inverter, then only one out of the three phases need to be switched.

This commutation scheme is implemented on the idea of using only the non-zero vectors to synthesize the reference vector. The hall sensors mounted on the motor will provide information on the present rotor position and this can be used as information to determine the region of the 2-level inverter. Then depending on the region identified two out of the three phases need to be clamped and only one phase needs to be switched depending on the state of the PWM signal. This commutation scheme will result in number of switching is minimum[6].

The logic sequence for the commutation scheme used in the proposed model is constructed and stored inside the EPROM which is simulated using a MATLAB „m-file“ written in to the user defined block. Table.1 Switching vectors and regions of the two level inverter and the corresponding phases to be clamped and the phases to be switched

Switching Vectors	Region	State of the phase
101,100	1	APH is clamped to Vdc, BPH is clamped to GND CPH will switched upon PWM
100,110	2	APH is clamped to Vdc, BPH will switched upon PWM CPH is clamped to GND
110,010	3	APH will switched upon PWM BPH is clamped to Vdc, CPH is clamped to GND
010,011	4	APH is clamped to GND BPH is clamped to Vdc, CPH will switched upon PWM
011,001	5	APH is clamped to GND BPH will switched upon PWM CPH is clamped to Vdc,
001,101	6	APH will switched upon PWM BPH is clamped to GND CPH is clamped to Vdc

The proposed commutation scheme utilizes the six non-zero switching vectors of the 2-level inverter to synthesize the reference vector at any instant It may be noted from Fig.3.6.1, that there are 6 regions. Consider the region numbered 1, the switching vectors are 101 and 100.

By inspecting these voltage vectors, it is found that APH is clamped to VDC, BPH is clamped to ground or zero voltage, CPH will be switched depending upon PWM. For each of the regions, similar switching strategy will be employed.

The reduction in the number of overall switching will result in lesser switching losses. Where APH represents the phase voltage of A, BPH represents the phase voltage of B, CPH represents the phase voltage, VDC represents the DC link bus voltage. Table II shows the Regions of the 2-level inverter and the corresponding phases to be clamped and the phase to be switched.

III. IMPLEMENTATION IN TMS320LF2407

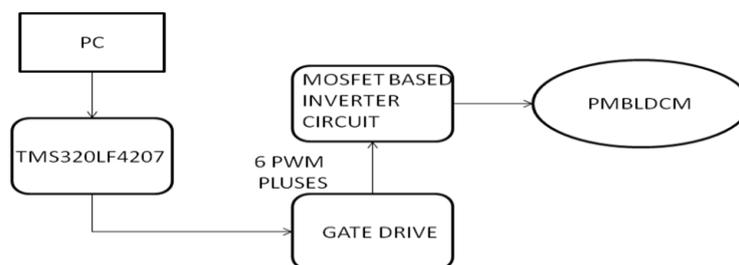


Fig .9 DSP controlled 3-phase PWM inverter fed PMBLDCM

TMS320LF2407 is a new generation controller with main frequency of 150MHz. The speed and features of this DSP make it an excellent choice for the digital control of motors. It has 16-pulse Width Modulation (PWM) output and 10-bit analog to digital converter. The fast conversion period, which is about 500ns, is very suitable for real time sampling. The motor control peripherals are ADC Module and Event Manager Module [14]. Fig 9 block diagram representation of speed control using TMS320LF2407.

The application of the PWM algorithm requires a time reference, a comparison mechanism, and digital outputs. Event Manager Modules of the DSP have the General Purpose (GP) Timer that can be used as time reference, Full Compare/PWM Units as a comparison mechanism, and have dedicated digital PWM outputs. Since there are two event manager modules in TMS320LF2407 called EVA and EVB, it has six independent pairs of PWM outputs; three of which are controlled by EVA and the other three are controlled by EVB [15]. The ADC module has sixteen channels and takes in input between 0 to 3V. The conversion time is 12.5 MSPS, which is very suitable for real time sampling as it has high accuracy. The start-of-conversion (SOC) sequence can be triggered by software, event manager or by external pin [16].

In order to design the most effective DSP system, code must be carefully optimized to make most of the available resources from the controller. Here assembly language programming is implemented which provides fastest execution and most compact form algorithm. The assembler in the host computer translates the assembly program into object code that can be downloaded into the the controller's program memory for execution. Software development tools are provided by the manufacturers of DSP controllers in developing efficient code for the controllers. Code composer studio from Texas Instruments is an integrated development environment that incorporates the C compiler, assembler, linker, simulator, debugger etc., with additional features such as graphical display for developing DSP software.[15].

IV. SIMULATION RESULTS

The simulation results includes variation of different parameters of BLDC motor like total output electrical torque (T_e), rotor speed (ω_r), rotor angle (θ), stator phase currents (i_a , i_b , i_c), back EMF's (E_{an} , E_{bn} , E_{cn}) with respect to time. Fig 9 represents the simulated waveforms for Back EMFs and fig.10 shows the simulated stator currents. Near sinusoid back EMFs and stator current waveforms are obtained because of the implementation of the proposed commutation scheme. In fig. waveform of motor position, Torque, speed are shown. From the fig. it is clear that ripple content is reduced in the developed electrical torque. Angular position of motor is shown in fig.11. It varies from 0 to 6.28 radians corresponding to 0° to 360° .

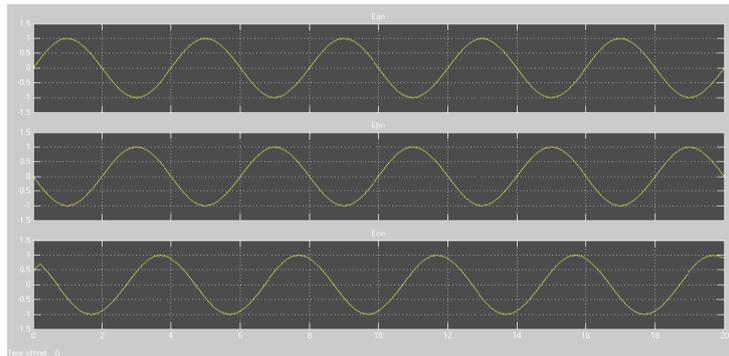


Fig.9 Waveform of back emf generated for phase A, phase B Phase C

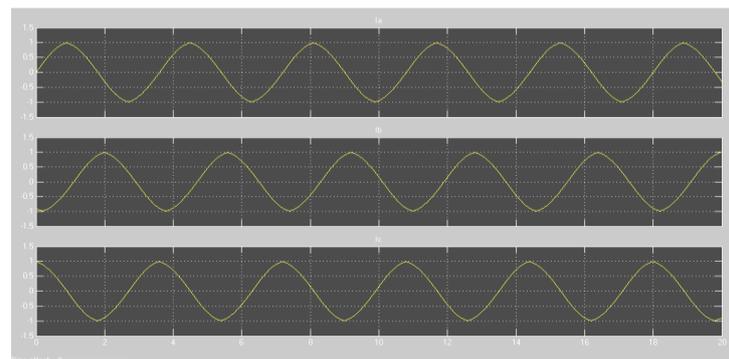


Fig .10 waveform of the Stator current for phase A, phase B, phase C

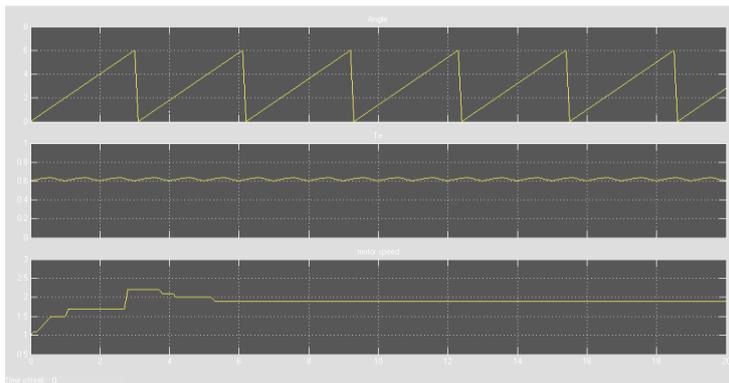


Fig.11 waveform of motor position, Torque, speed

V. CONCLUSION

In this work the digital speed control of BLDC Motor which is carried out by the implementation in DSP controller TMS320LF2407 is explained in detail. The complete model is simulated in MATLAB/SIMULINK. Based on the classical modeling of the BLDCM, the modeling and simulation of the control system is also explained in detail. The simulation results are presented. In this paper the features and motor control peripherals of TMS320LF2407 is also discussed. The programming for the control algorithms is done in C language which provides the fastest execution and most compact and optimized form of algorithm. The loading of code onto the DSP is carried out by using Code Composer Studio IDE platform.

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