DSP based Speed Control of Permanent Magnet Brushless DC Motor

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ABSTRACT

This paper presents digital speed control of permanent magnet brushless dc motor using TMS320F2812 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 assembly language programming in TMS320F2812 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 TMS320F2812.

Keywords

Brushless DC Motor, DSP controller, Pulse Width Modulation(PWM), TMS320F2812.

1. INTRODUCTION

The demand of PMBLDC motors in high power servo applications is increased because of its High efficiency due to reduced losses, low maintenance and low rotor inertia. Also the invention of modern solid state devices like MOSFET, IGBT and high energy rare earth Permanent Magnets have widely enhanced the applications of PMBLDC motors in variable speed drives. There has been a continuous demand to reduce the control hardware and thus cost of this drive. In this work, a digital controller is developed which uses minimum number of components employing a recently introduced DSP controller (TMS320F2812) by Texas Instruments (TI) for power electronics applications [1],[2].

Traditionally inexpensive analog components are used for the design purposes of Motor drives . The weakness of analog systems is their susceptibility to temperature variations and component aging. Another drawback is the difficulty of upgrading the systems. Digital control structures eliminate drifts and, by using a programmable controller, the upgrades can be easily accomplished by software. The high performance of digital signal controllers allows them to perform high-resolution control and minimize control loop delays. These efficient controls make it possible to reduce torque ripples, harmonics and improve dynamic behavior in all speed ranges. The motor design is optimized due to lower vibrations and lower power losses such as harmonic losses in the rotor [6].

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 [7],[8].

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 TMS320F2812 DSP controllers are designed to meet the needs of control-based applications. At 20 million instructions per second (MIPS), DSP controllers offer significant performance over traditional 16-bit microcontrollers and microprocessors[10]-[12].

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 TMS320F2812. 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. commutation. The simulation was carried out in MATLAB/Simulink environment.

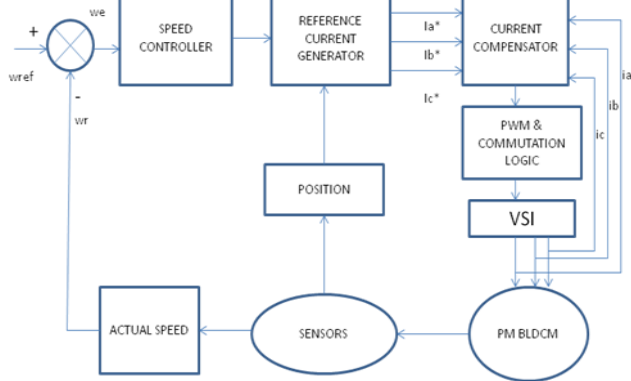## 2. ESTABLISHMENT OF A SIMULATION MODEL BASED ON MATLAB/SIMULINK

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 [2]. The Complete Simulink Model is as shown in Fig 2.Different subsystems of the simulink model are discussed in detail.
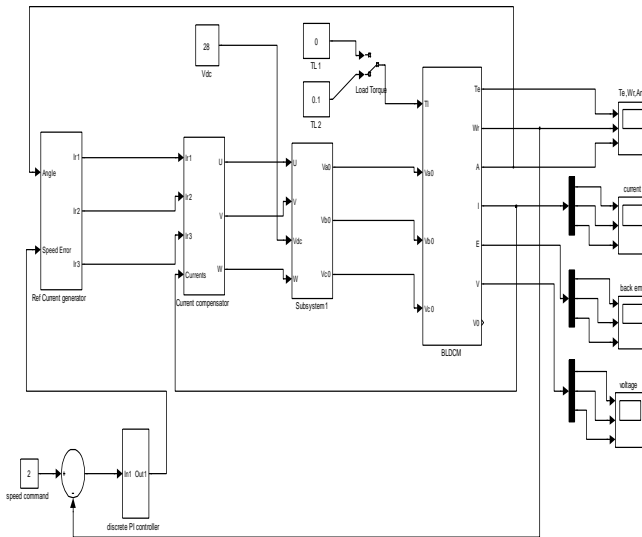

Fig.2 Simulink model

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.
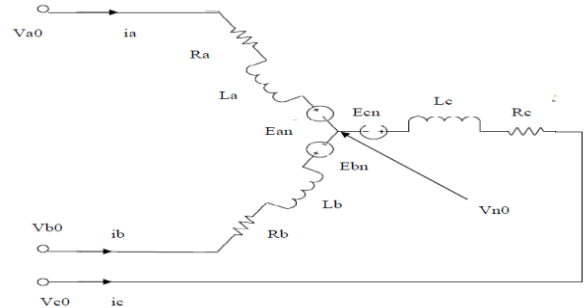

Fig .3 The equivalent circuit of BLDCM

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 [2].Classical Modeling equations involves,

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

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,

Stator resistance per phase,$R_a =R_b=R_c=R$ and inductance per phase.,$L_a=L_b=L_c=L$

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

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

$$V_{bn}=V_{b0}- V_{no} \qquad (3)$$

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

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

Also

$$V_{an}=i_aR_a+L(di_a/dt)+E_{an} \qquad (5)$$

$$V_{bn}=i_bR_b+L(di_b/dt)+E_{bn}$$
(6)

$$V_{cn}=i_cR_c+L(di_c/dt)+E_{cn} \qquad (7)$$

Where,i_a , i_b , i_c Stator phase currents.Back EMFs will be of the form

$$E_{an}=w_r*k_b*sin(\theta) \qquad (8)$$

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

$$E_{bn}= w_r * k_b *sin((\theta)-(4* \pi)/3) \qquad (10)$$

From which the stator Phase currents are estimated as,

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

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

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

Total electrical torque developed ,

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

From the dynamic model equation of motion of the motor,

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

Where,

j- Moment of inertia,B- Friction constant

Again we know,

$d(\theta)/dt= w_r$ (16)

from which rotor displacement can be found out as,

$\theta=(1/s)*w_r$ (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.
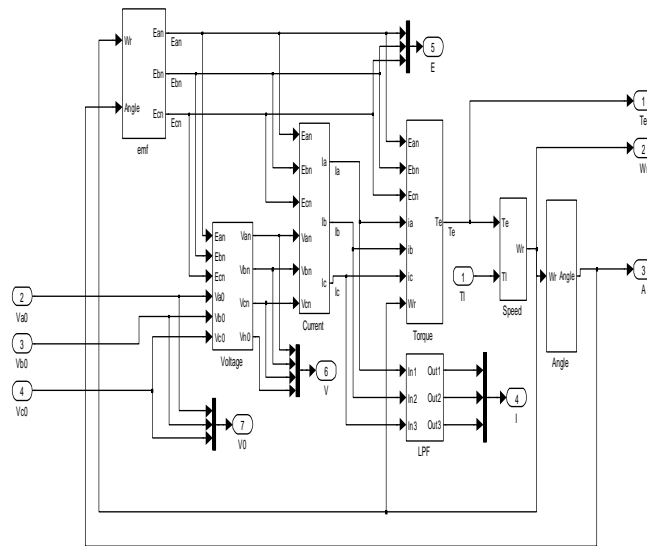

Fig .4 BLDCM sub block

2.2 Digital PI controller

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

$w_{e(n)}=w_{r(n)}*-w_{r(n)}$ (18)

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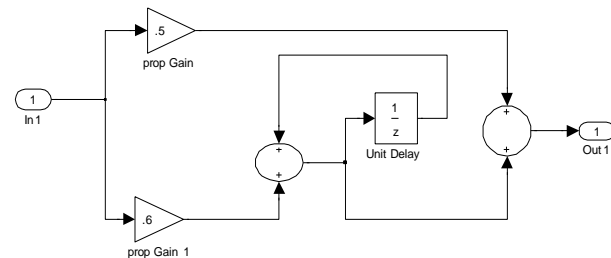

Fig 5.Digital PI controller

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* . K_b. Depending on the rotor position, the reference current generator block generates three-phase reference currents (i_a * , i_b * , i_c*).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.
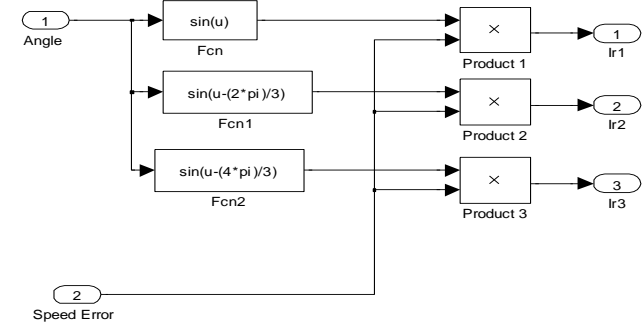

Fig .6 Reference current generator

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.7
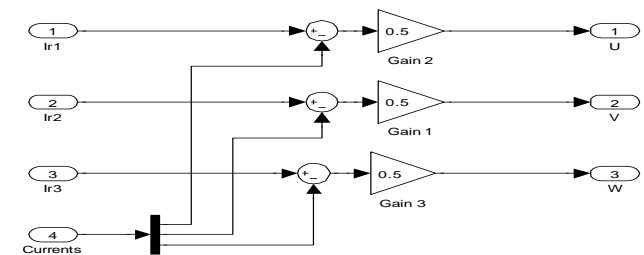

Fig .7 Current Compensator

2.5 Novel 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[4],[5].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 [3]. The six active non-zero vectors are located at the vertices of a hexagon. The hexagon is divided into six regions marked 1 – 6.
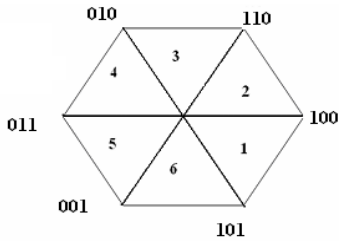

Fig .8 Switching vectors used in the commutation scheme

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 to be minimum[3],[5]. 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 depends upon PWM
100,110	2	APH is clamped to Vdc,BPH will switched depends upon PWM CPH is clamped to GND
110,010	3	APH is clamped to Vdc,BPH is clamped to GND CPH will switched depends upon PWM
010,011	4	APH will switched depends upon PWM ,BPH is clamped to Vdc CPH is clamped to GND
011,001	5	APH is clamped to GND,BPH will switched depends upon PWM CPH is clamped to Vdc
001,101	6	APH will switched depends 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.2, 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 loses. 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 [5].
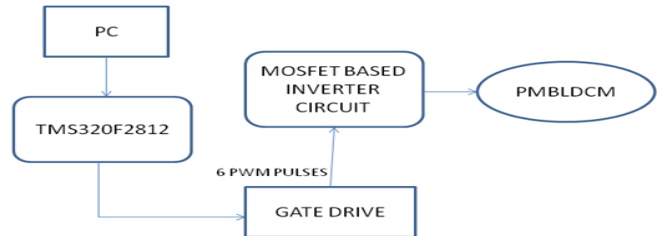
3. IMPLEMENTATION IN TMS320F2812

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

TMS320F2812 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 12-pulse Width Modulation (PWM) output and 12-bit analog to digital converter. The fast conversion period, which is about 80ns, is very suitable for real time sampling. The motor control peripherals are ADC Module and Event Manager Module [12].Fig 9 block diagram representation of speed control using TMS320F2812.

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 TMS320 F2812 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 [13]. 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 [14].

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 lanquage 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] .

4.   SIMULATION RESULTS

The simulation results includes variation of different parameters of BLDC motor like total output electrical torque (Te), rotor speed (w_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..Fig10,11,12 represents the simulated waveforms for Back EMFs and fig.13,14,15 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 fig16 waveform for motor torque is shown. From the fig. it is clear that ripple content is reduced in the developed electrical torque.Fig.17 shows the waveform for the speed. Angular position of motor is shown in fig.18.It varies from 0 to 6.28 radians corresponding to 0˚ to 360˚.
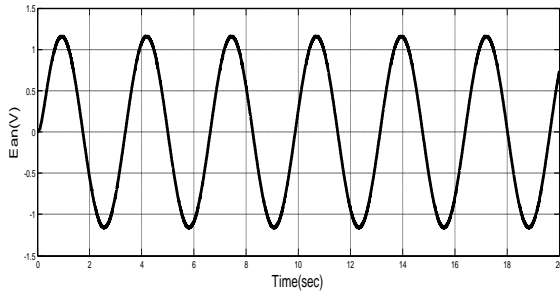

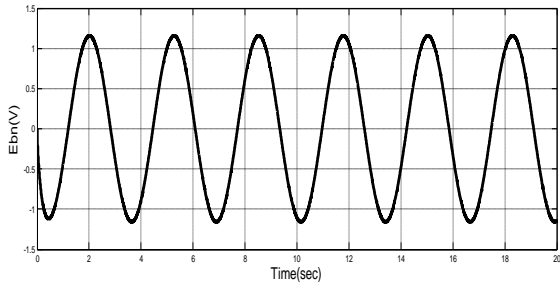Fig.10 Waveform of back emf generated for phase A

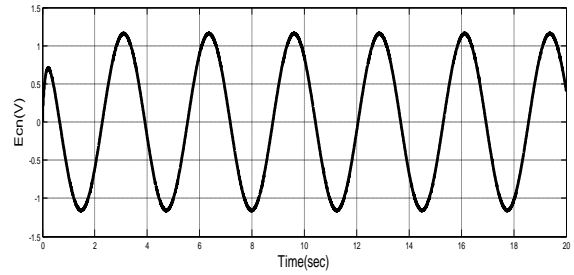Fig.11 Waveform of back emf generated for phase B

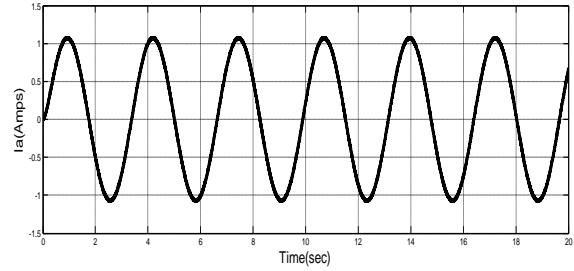Fig.12 Waveform of back emf generated for phase C

Fig .13 waveform of the Stator current for phase A
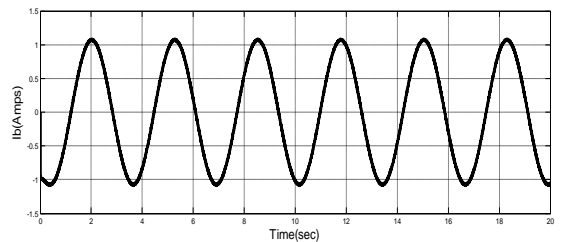

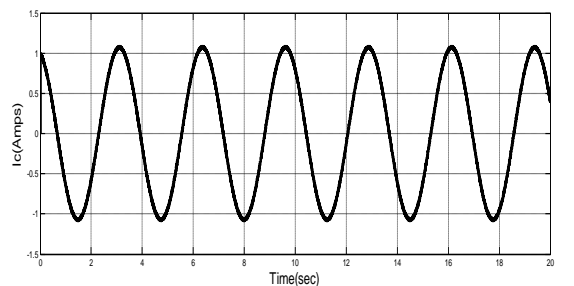Fig .14 waveform of the Stator current for phase B
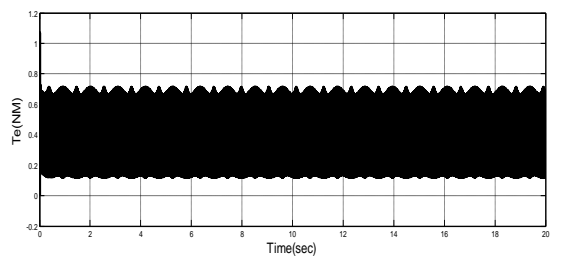

Fig .15 waveform of the Stator current phase C
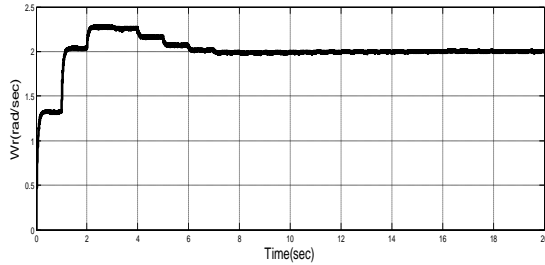

Fig .16 Motor Torque
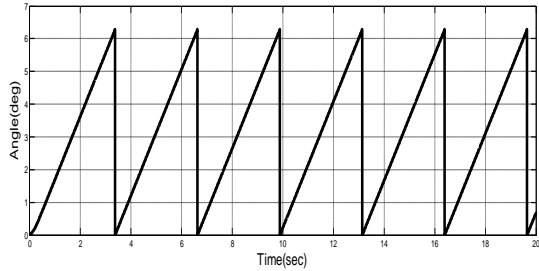
Fig .17 Motor speed

Fig .18 Motor position

5. CONCLUSION

In this work the digital speed control of BLDC Motor which is carried out by the implementation in DSP controller TMS320F2812 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 TMS320F2812 is also discussed. The programming for the control algorithms is done in assembly lanquage 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.

6. ACKNOWLEDGMENTS

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