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Stability Analysis of ARM-Based Control of Brushless DC Motors Using Digital PWM Technique

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Abstract **— A synchronous motor with a permanent magnet in the rotor and operated in self controlled mode using a rotor position sensor and an inverter to control current in the stator winding is generally known as a Brushless DC motor. The BLDC motor is an inside out brushed motor because the armature is in the stator and the magnets are in the rotor and its operating characteristics are similar to those of the conventional brushed Dc motor. The brushless DC motor (BLDCM) is receiving wide attention for industrial applications because of their high torque density, high efficiency and small size. Brushless DC motor (BLDC) The objective of the paper is to develop a digital Pulse Width modulation (PWM) technique speed control algorithm for BLDC motor and also reduce harmonic content that should be produced by inverter during switching time in Kiel Arm software which is an environment for model based development of embedded controller for ARM processor. In this paper ARM 7 processor is used as the controller necessary signal conditioning components are used to ensure high speed and precision in the overall control system. The implemented system has a fast response with very small overshoot and zero steady state error compared to conventional PWM current controller.**

Index Terms**—BLDC motor, conventional PWM current controller, Digital PWM controller, Kiel.**

I.INTRODUCTION

Since the late 1980s new design concept of permanent magnet brushless motors has been developed. The permanent magnet brushless motor can be classified into brushless DCBLDC or Brushless AC BLAC motor modes. In modern electrical machines industry brushless Dc motor more popularity. BLDC motor are more used in such as medical, electric traction, military equipment, hard disk drive etc. BLDC motor has a trapezoidal back-emf and is referred to as the brushless Dc (BLDC) motor. Comparing BLDC motors with Dc motors, The Dc motor have high starting torque capability, smooth speed control and the ability to control their torque and flux easily and independently.[1] In the Dc motor the power losses occur mainly in the rotor which limits the heat transfer and consequently the armature winding current density while in BLDC motor the power loss are practically all in the stator where heat can be easily transferred through the frame or cooling systems can be used specially in large machines.

Permanent magnet alternating current (PMAC) motors are also called as synchronous motors that have permanent magnets mounted on the rotor and polyphase, usually three phase, armature windings located on the stator .since the field is provided by the permanent magnets PMAC motor has higher efficiency than induction motor or switched reluctance motors. It also draws better power factor and has higher power density. The advantages of PMAC motors combined with a rapidly decreasing cost of permanent magnets, have led to their widespread used in many variable-speed drives such as robotic actuators and heating-ventilating –air conditioning (HVAC) equipment. In general PMAC motors are categorized into two types. The first type of motor is referred to as PM synchronous motor (PMSM) these motors produce a sinusoidal current/voltage. The PMSM electronic control and drive system uses continuous rotor position feedback and pulse width modulation (PWM) to supply the motor with the sinusoidal voltage or current. With this constant torque is produced with very little ripple.

The BLDC drive system is based on the feedback of rotor position which is not continuous as with the PMSM but rather obtained at fixed points typically every 60 electrical degrees for commutation of the phase currents.[2]The BLDC motor requires that quasi rectangular shaped currents are fed into the machine. Alternatively the voltage may be applied to the motor every 120 degree with a current limit to hold the currents within the motors capabilities. Because the phase currents are excited in synchronism with the constant part of the backemf constant torque is generated.

Effect of generating a measurable voltage by magnetic field is called the Hall Effect sensor type semiconductor material such as gallium arsenide (GaAs) passes continuous current through itself. When device is placed within a magnetic field magnetic flux lines exert a force on the semiconductor slab. This movement of charge on semiconductor exerts a holes and electrons sidewards a potential difference is produced between the two sides of the semiconductor material affected by the presence of an external magnetic field which is at right angles to it. This effect is greater than rectangular shaped material.

In figure (1) shows that Commutation of a BLDC motor is controlled by electronic commutator to rotate motor continuously or sequence stator coil that should be sequentially energized .rotor position sensed using Hall Effect sensor embedded in stator. Mostly three Hall Effect sensors embedded into the stator on the non driving mechanism end of motor. Each and every time magnetic poles crosses Hall Effect sensors sense the high or low signal indicating north or South Pole passing near to sensor. Based upon that exact sequence we determined or obtained.

II. THEORY OF OPERATION

The basic of operation of the BLDC motor is shown in figure 1 switches direct the direct from a DC source through a coil on the stator. The rotor consists of a permanent magnet. In figure 1(a) the current flows in the direction that magnetizes the stator so that the rotor is turned clockwise as shown. In 1(b) the rotor passes between the poles of the stator current is switched off, Momentum carries the rotor on and in 1(c) the stator coil is re-energized but the current and hence the magnetic field are reversed. So the rotor is pulled on round in a clockwise direction. The process continues with the current in the stator coil alternating.

Obviously the switching of the current must be synchronized with the position of the rotor. This is done using sensors. These are often Hall Effect sensors that use the magnetism of the rotor to sense its position but optical sensors are also used. A problem with the simple single coil system of Figure 1 is that the torque is very unsteady .This is improved by having three (or more) coils as shown..In this diagram coil B is energized to turn the motor clockwise. Once the rotor is between the poles of coil B, coil C will be energized, and so on. The electronic circuit used to drive and control the coil currents is usually called an inverter and it will be the same as or very similar to our universal inverter circuit. The main control input to the ARM processor will be the position sense signals.

Voltage on the motor determines speed and current in the motor determines torque .These characteristics are linear and nearly identical to a standard Brush DC drive. A feature of these BLDC motor is that the torque will reduce as the speed increases. The rotating magnet will generate a back emf in the coil which it is approaching. This back emf will be proportional to the speed of rotation and will reduce the magnetic field strength and hence the torque. Eventually the size of the induced back emf will equal the supply voltage and at this point the maximum speed has been reached.

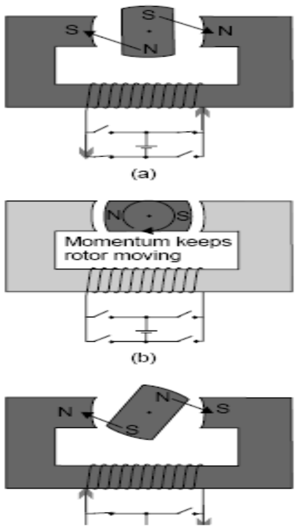

Fig.1 BLDC Motor Operation

A.Commutation Sequence

Every 60 electrical degree of rotation, one of the hall sensors should changes their state. Six steps need to complete one electrical cycle. In synchronous with hall sensor electric current should be updated. Electrical cycle may not correspond with mechanical revolution of motor. Depending upon their rotor poles pair's electrical cycle desired. Each rotor pole pairs complete one cycle revolution. So that we conclude depending upon rotor pole pairs should be equal to electrical cycle. Several methods for speed control available in that we taken Pulse width modulation technique it should be control the dc bus voltage is greater than the motor rating voltage it should simply control their PWM duty cycle. Different approaches of controls PWM signals are limited in the ARM processor upper switch turned on for entire time during corresponding sequence as a same time lower switch control by required duty cycle on PWM.

Speed can be controlled in a closed loop by measuring actual speed and reference speed of the motor. The error in the set speed and actual speed is calculated. A proportional plus integral (P.I.D) controller and conventional PWM current controller used to amplify the speed error and dynamically adjust the PWM duty cycle.

B. Torque/ Speed Characteristics

The magnitude of the flat-topped phase emf is given by:-

$e=2N_{ph}B_grlwv$………(1)

Where
Bg - flux density in air gap (wb/m2)
r - Radius of the air gap (m)
l – Length of the armature (m)
Wm - angular velocity in mech.rad/sec
Tph – number of turns per phase

p=WTe=2eI…………(2)

The '2' in this equation arises from the fact that two phases are conducting using the expression derived above for the emf the electromagnetic torque is given by

$Te=4N_{ph}B_grlwv$………(3)

In practice of course none of the ideal conditions can be perfectly realized. The main result of this is to introduce ripple torque, but the basic relationships of e.m.f proportional to speed and torque proportional to current remain unchanged. If phase resistance is small as it should be in an efficient to design, then the characteristics are similar to that of a shunt dc motor. The speed is essentially controlled y the voltage v, and may be varied by varying the supply voltage; the motor then draws just enough current to drive the torque at this speed.

ω =V×Kspeed………..(4)
Where Kspeed is the motor speed constant in radians per volt. It is clear that the motor speed is directly proportional to the applied voltage, V.

III.DIGITAL PWM CONTROLLER TECHNIQUES

This paper presents the design, simulation, and experimental Verification of a novel constant-frequency digital PWM controller which has been designed for a BLDC motor drive system. In essence, the controller treats the BLDC motor as a digital system [3] The concept of this digital controller is very simple. Speed regulation is achieved by using two levels of duty cycles—a high duty (*DH*) and a low duty (*DL*). The rules of the digital controller can be explained using the flowchart shown in Fig 2[4] unlike a hysteresis current controller, a PWM control does not have an inherent current control capability. Hence, a current limiter has to be introduced. Current hysteresis digital controllers have been reported for a BLDC motor. This paper presents a controller with no need of any state observer. Fig.4 shows the proposed digital controller shows the complete block diagram of the motor drive system.

A proportional controller provides the reference for the current limit. The current is made to stay within a maximum and minimum limit. The maximum value of *I* limit is 1.5 times the rated motor current[5]This is because motors can handle 1.5 times the rated current for a short duration of time. The minimum value of *I* limit decides the steady-state error. For a Value equal to zero, a large steady-state error is observed in the simulation. The minimum value of I limit is defined as the Ratio of a percentage (1%) of the rated torque to the torque Constant [6]

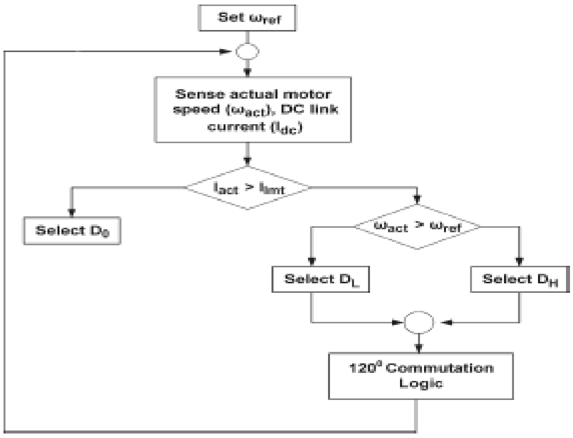

Figure 2 Flow Chart for proposed digital controller

The main principle of digital PWM control strategy is shown in Fig.3. This control strategy treats the BLDC machine as a digital system. In other words, one of only two predetermined values of PWM duty cycles are applied to the IGBT switches based on speed error, i.e., the drive can operate in two possible states: state 1 (a high value of PWM duty cycle *DH* is applied to inverter switches) or state 2 (a low value of PWM duty cycle *DL* is applied).

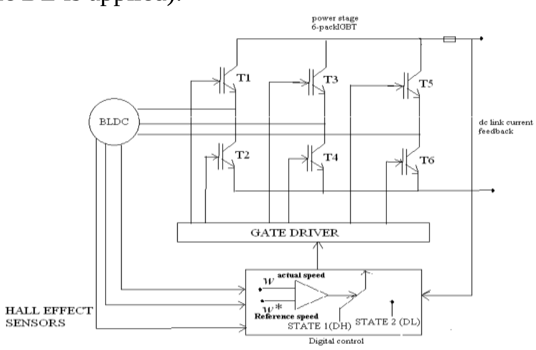

Figure 3 block diagram of digital PWM controller

In other words, the digital controller essentially generates PWM signals and converts them into commutation functions for the power switches based on logic obtained for the speed regulator[7] Digital control algorithm is basic and takes actual speed and reference speed as only inputs, while the output is

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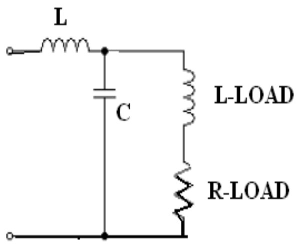
PWM logic signal for gates of the inverter switches. Such PWM voltage control is uncomplicated to put into practice; however, it is advisable to include over current protection in the form of a dc-link current sensor to ensure the safe operation of the machine [8]

A. Filter Design

The selection of LC component present in the filter plays a major role in the performance of the drive. The charging and discharging of the capacitor improves the quality of the voltage given to the motor. The BLDCM is energized by the three phase inverter through an inductor - capacitor filter for reducing the high frequency component. The capacitor voltage value has to be selected in such a way that it can charge and discharge in an effective manner to reduce the high frequency Component[9] The inductor present in series with each phase will reduce the commutation current pulsation and thereby reducing the jerk produced by commutation effects.

To design the reactive elements present in the filter, it is assumed that the capacitor which is connected across the load is large enough to charge and discharge, hence the capacitor voltage may be considered to be nearly constant[10]The inductor current rating should be equal to the current ratings of the motor.



Now the peak inductor current equal to
IPEAK=2Vm/Zmin
Where Zmin is the minimum value of load impedance, Vm is the peak magnitude of the phase voltage.

The capacitance of the filter is C=Vm/2ZMINfsw((del)V) is the ripple voltage at the input of the filter.

Is the switching frequency of the inverter power devices that is equal to the ripple frequency[11],[12],[13].T on and t off are the on time and off time of the power devices
Ton+Toff=1/fsw
L= (Vs-Vo)/Ipeak)*ton
Vs is the source Voltage of the filter and Vo is load Voltage[14].

IV.RESULTS AND DISCUSSION

The proposed algorithm has been programmed in MATLAB 2011a. And it generates the firing pulses required to drive the MOSFETs of three phase fully controlled bridge converter. The program has been dumped on to the ARM 7series device and fed to the MOSFETs of three phase fully Controlled bridge converter driven by driver circuit. And also we using designing an modified sinusoidal PWM technique to minimize low order harmonics as well as LC filter reduce Higher order harmonics.The output from the converter is fed to the three phase stator winding of 24V, 80 W, 1A, 2000 rpm BLDC motor and the motor is found to run at constant speed which is set by the external Potentiometer connected to the microcontroller circuit. The program is found to be efficient and the results with the designed simulation are promising.

In this section we are discussion about simulation results for transients and stability of digital control of BLDC motor parameters such as overall simulation block of BLDC motor, subsystem block of digital controller, stator current, back emf, speed, torque characteristics that should been taken from mat lab simulation.

From that above simulation diagram we design closed loop control speed regulation of BLDC motor using digital PWM controller. The below simulation block diagram shows digital control for BLDC drive.

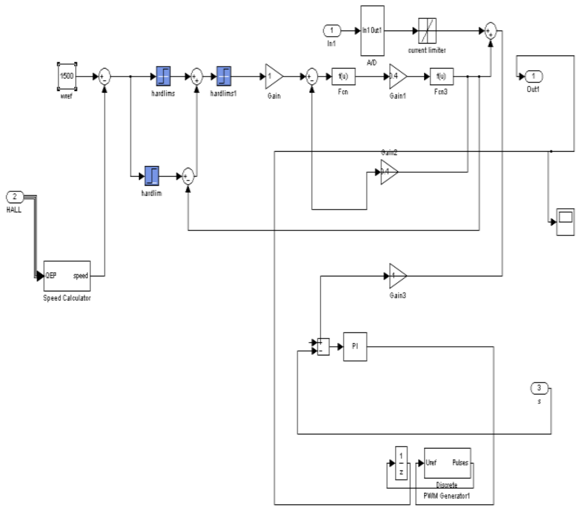
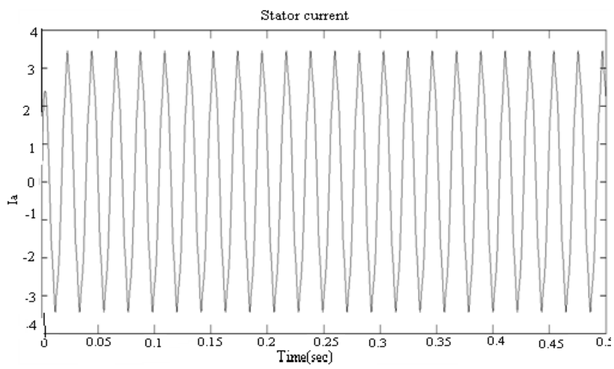
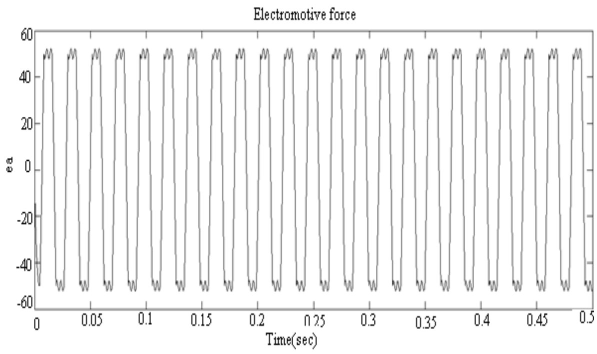


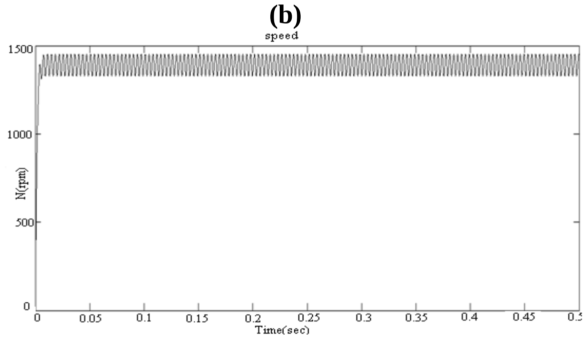
Figure 4 Subsystem block for digital controller
The digital controller for BLDC drive



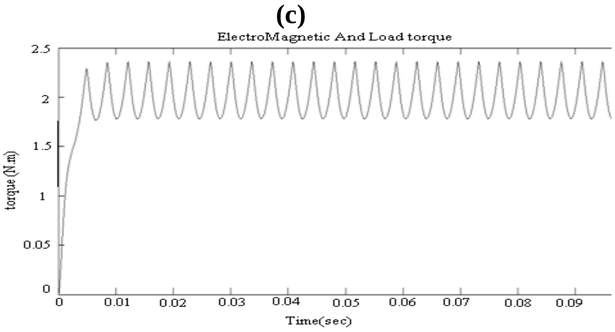
(a)



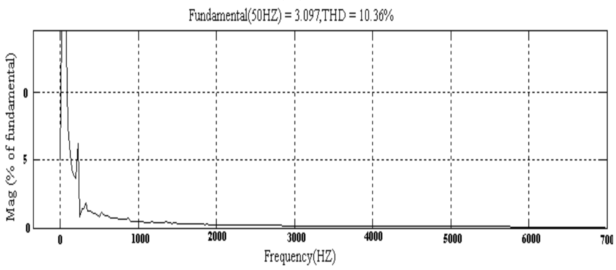
(b)



(c)



(d)



(e)

Fig.5.a) Stator current b) electromotive force C) speed d) Electromagnetic and load torque e) fundamental harmonic

V.CONCLUSION

This paper presents an approach for the implementation of a digital PWM controller for BLDC motor on an ARM using Kiel. The implementation of the digital PWM controller is very straightforward by coding each component system in Kiel according their specifications of BLDC motor.

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