

Study of Multi quadrant Operation of a BLDC Motor with Digital Implementation

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ABSTRACT: BLDC motors are nowadays extensively used in wide range of applications due to its high efficiency and improved performance characteristics. In the modern applications like spindles, fast conveyor belts and electric vehicles, where there is continuous change in direction of the motor, multi quadrant operation need to be utilised effectively. Multi quadrant operation has its own limitations like sparking and considerable power loss during the quadrant transitions from one to another. This proves the requirement to implement the multi quadrant operation digitally. This paper presents a review on the digital implementation for the multi quadrant operation of a BLDC motor. The digital control has been verified and results were obtained using MATLAB/Simulink.

KEYWORDS: BLDC motor, speed-torque characteristics, Multi quadrant operation, regenerative braking, digital control.

I. INTRODUCTION

Brushless DC (BLDC) motors are becoming more popular in all range of modern day technological applications in the areas of aerospace, automotive, industrial, medical and robotic applications. The better speed-torque characteristics, high efficiency, high dynamic performance, long operating life and noiseless operation make it suitable for its wide range of applications.

A three-phase synchronous motor with three-phase concentrated windings on the stator and permanent magnets on the rotor is what is referred to as a brushless DC motor. A BLDC motor is also referred to as electronically commutated motor (ECM) since it does not have a mechanical commutator. Electronic commutation for a BLDC motor is provided by means of hall sensors that determine the rotor position at each instant. These instants are decoded and then corresponding coils are energized further to enable continuous rotation of the motor. Hence a BLDC motor requires a six step inverter that provides rectangular voltage strokes which energizes the windings as per the rotor position. Absence of mechanical commutator enables easy maintenance and its lower inertia account to faster dynamic response. Also they have increased efficiency due to the permanent magnets, which contribute to the lower rotor losses [1].

Multi quadrant operation is when all the four quadrants of the speed-torque profile of a motor is utilised. Motoring operation occurs when both speed and torque is in same direction whereas braking occurs both speed and torque is in opposite direction. The first quadrant is called forward motoring since speed is in forward direction. The second quadrant is called forward braking. The third quadrant is called reverse motoring since speed is in reverse direction and the fourth quadrant is called reverse braking. Multi quadrant operation finds its applications like spindles, fast conveyor belts, modern hybrid electric vehicles and aerospace drives. These all applications indicate frequent speed reversals. Motor drives when change their direction from one quadrant to other undergo considerable power loss as they take some amount of time for the quadrant transition. In the conventional multi quadrant operation of any motor, the motor when receives a speed reversal command first comes to the stand still position and then from the stand still position it rotates through the other direction. The slow reversal can induce sparking and the more time it takes to reverse its speed, more the power loss. This facilitates the need of digital implementation. With digital control, the time gap required for quadrant transition can be reduced effectively and the other problems like sparking can also be avoided.[2]-[5].

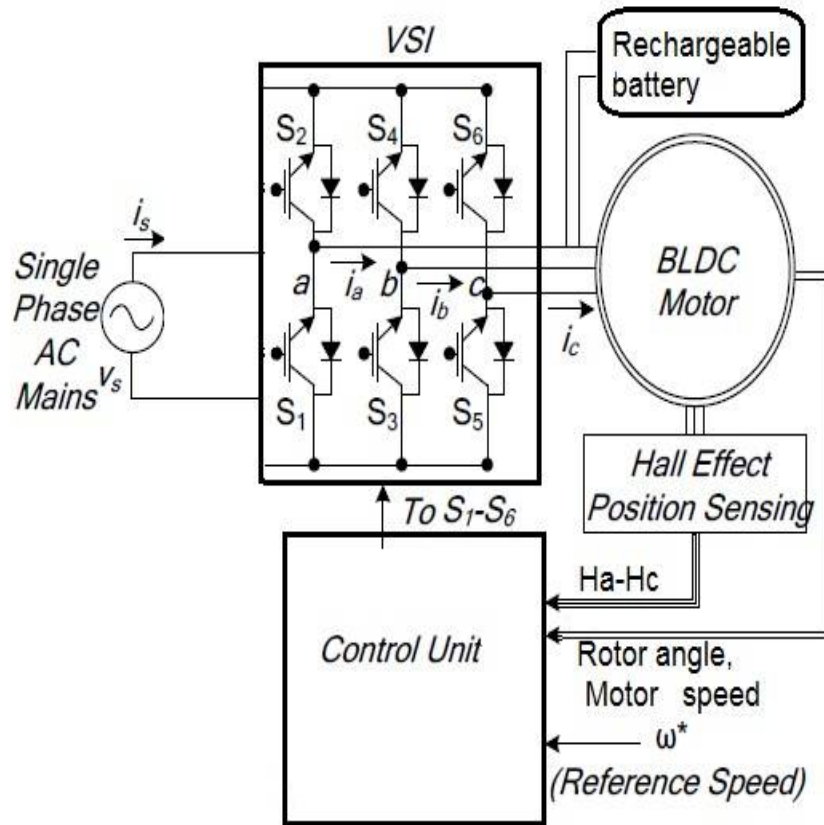


Fig 1: Block diagram for the BLDC motor system

The work in this paper is divided in two categories. 1) Multi quadrant operation 2) Digital Implementation. Section II describes the overall system. Section III explains the simulation results obtained. Section IV finally presents the conclusion of the paper.

II. WORKING OF THE SYSTEM

The block diagram for the system is shown in Fig.1. The digital implementation is carried out by continuous energisation of the main phase during quadrant reversal in the multi quadrant profile. The BLDC motor is initially made to rotate in clockwise direction, but when the speed reversal command is obtained, the control goes into the clockwise regeneration mode, which brings the rotor to the standstill position. Instead of waiting for the absolute standstill position, continuous energization of the main phase is attempted. This slows down the rotor to a standstill position rapidly than the conventional case. Thus power loss occurring due to any quadrant change of the BLDC motor can be reduced. The speed reversal commands can be provided with relay circuits. The braking power during the braking mode operation can be stored in a battery. Thus energy wastage problem can also be solved [6]-[7].

Here is the necessity for determining the rotor instants when the rotor of the machine is ideally positioned for reversal. Hall effect sensors come into the role now. The hall sensors for each phase are used to ascertain the rotor position of the BLDC motor and from the Hall sensor outputs, it is determined whether the machine has reversed its direction. This determines the moment for energizing the stator phase so that the machine can start motoring in the counter clockwise direction. The concept of digital implementation of multi quadrant operation makes it potential in most modern applications, especially in applications like conveyor belts and spindles, where direction change is an important parameter. The digital implementation of switched reluctance motor has been studied and similar principle is applicable for BLDC motor also [8].

The variant quadrant operations are obtained by controlling the pulse width modulation to the motor system. The hall sensor outputs determine the instants at which the switches in the voltage source inverter are to be turned on. The duration of the gate signal is controlled by the feedback system. The motor speed is compared with the reference speed and then fed to the PI controller to generate the gating signal.

III. SIMULATION RESULTS

A 3000rpm, 1.7 Nm, 300V BLDC motor is used as the simulation model motor. The overall simulation circuit is shown in Fig.2. The proportional and integral constant values are obtained by tuning the controller. The Kp value is set as 10.7 and Ki is 0.15.

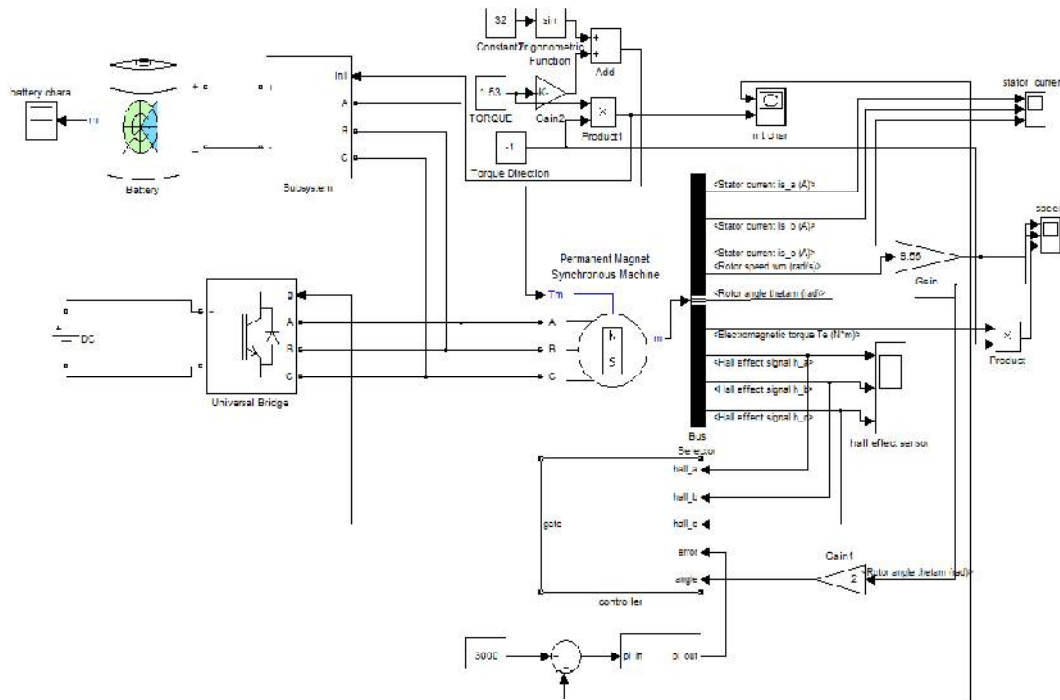


Fig 2.Simulink Model

The simulated results are obtained for the different quadrant operation as well as the stator current, hall sensor output and closed loop speed, torque and angle characteristics for the BLDC motor. Fig 3(a) and 3(b) shows the stator current and hall sensor outputs. The stator currents are square in nature since back emf is trapezoidal in shape for a BLDC motor.

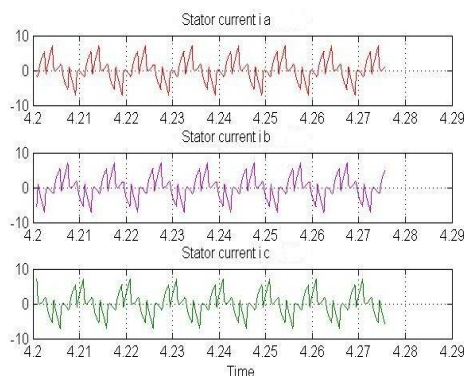


Fig.3(a): Stator currents

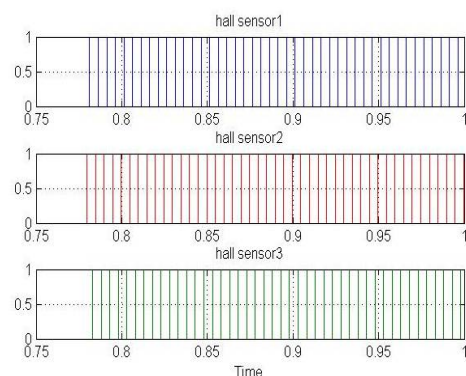


Fig.3(b): Hall Sensor Output

The different speed-torque profiles for a reference speed of 3000rpm and torque of magnitude 1.5Nm are shown in the following figures: Fig 4(a), 4(b), 4(c) and 4(d).

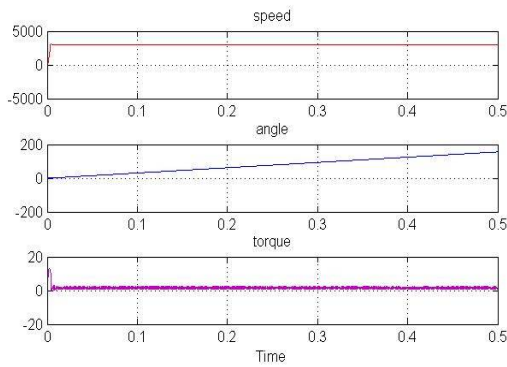


Fig.4(a) : Quadrant I operation

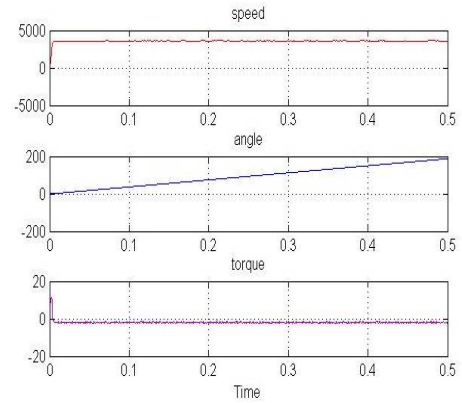


Fig.4(b): Quadrant II operation

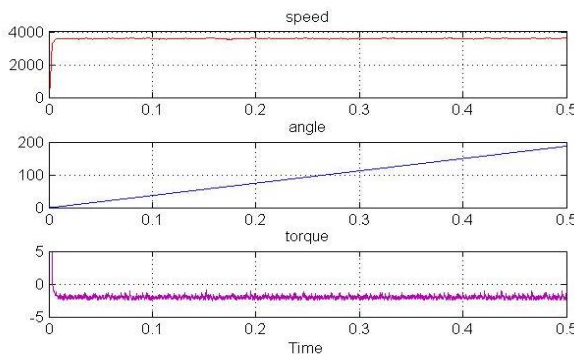


Fig.4(c) : Quadrant III operation

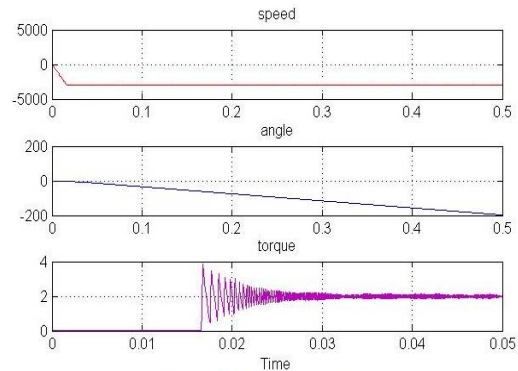


Fig.4(d) : Quadrant IV operation

Fig.4 Output voltage and output current waveforms of seven-level inverter

IV. CONCLUSION

A digitally implemented multi quadrant operated BLDC motor is simulated using MATLAB/Simulink and results were obtained for various quadrants indicating speed, torque and angle variations. The significant advantages of the proposed work include simple hardware circuit, reliability of the control algorithm, excellent speed control, smooth transition between the quadrants and efficient conservation of energy is achieved with and without load conditions. The designed and implemented prototype model may be implemented even for higher rated motors. Arcing might occur during the switching on and off of the relay contacts, when implemented in higher rating motors.

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