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Implementation of Four Quadrant Operation of BLDC Motor Using Model Predictive Controller

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Abstract

This paper proposes a method that designs a simulation model of four quadrant operation of BLDC motor drive and to reduce the torque ripples. In the developed model, the characteristics of speed, torque, back EMF are effectively monitored and analyzed. The Model Predictive Controller (MPC) enables to control the motor in all the four quadrants without any loss of power; to note, energy is conserved during the regenerative period. MATLAB/SIMULINK model is used for software simulation. Hardware implementation has been carried out for the verification of proposed control scheme.

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1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper.

During the 19th century, the vector control (VC) or field oriented control (FOC) scheme resulted in a significant improvement in the performance of electrical drives. . However, these schemes have several main limitations, such as the high sensitivity to machine parameters and large computing cost. Energy saving is the main aim behind all the development control of motors. DC conventional motors have good control characteristics but their performances are reduced due to commutation problems. BLDC motors, also called Permanent Magnet DC Synchronous motors, are one of the motor types that have gained popularity, mainly because of their better characteristics and performance. These motors are seen always in industrial sectors because their architecture is much suitable for any safety critical applications. In the literature, BLDC motor is a synchronous electric drive that, from a modelling perspective [1-2], the regenerative braking system based on signal processing for single quadrant operation [3], four quadrant operation on switched reluctance motor drive [4], four quadrant operation of BLDC motor based on signal processing [5], four quadrant operation of brushless DC motor with hysteresis controller [6], torque control of small inductance in BLDC [8]. In this paper the analysis of four quadrant operation of BLDC motor is studied on MPC technique. Also a torque controller is designed to reduce the ripples content present in existing system. The proposed work have many advantages such as good efficiency, long operating life, high speed ranges, noiseless based operation etc. These qualities of BLDC motor results in growing applications like aerospace, automation, computers robotics, electric vehicles etc.

2. Four Quadrant Operation of BLDC Motor

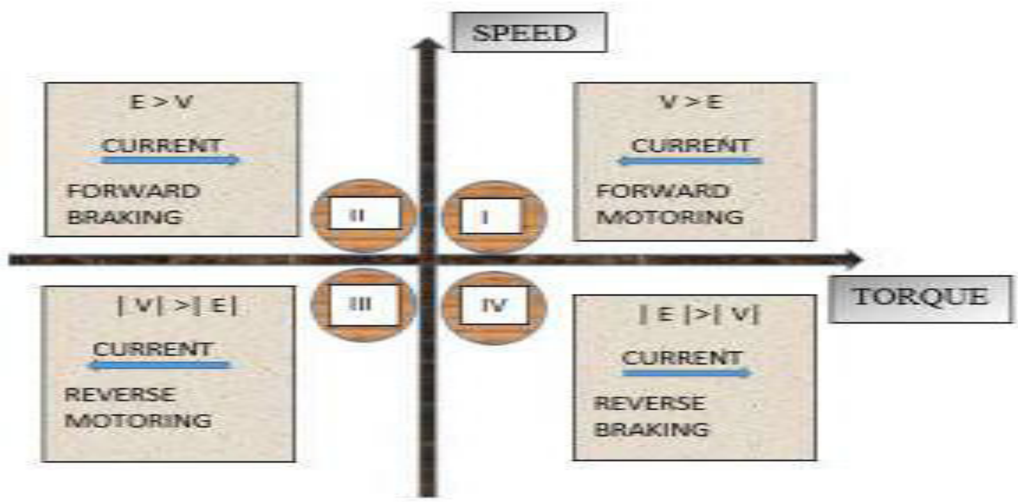

Fig.1. Four Quadrant Operation with Operating Modes.

The existing DC motors are highly efficient and their electrical characteristics suit for use of servomotors. However, their major drawback during running condition is the need for commutator and brushes which requires high maintenance. As a result, in BLDC motor there are no brushes and commutator and thus all the drawbacks which are connected with the flashing of brushes are neglected. This BLDC motor is called to as a DC motor because its coils are driven by DC power supply. The DC power is given to the windings of stator. Now there are possible four modes or quadrants of operation using a Brushless DC Motor which is shown in Fig 01. When we plot X-Y of speed versus torque, Quadrant I is forward with speed and torque. The torque is propelling the motor in the forward direction. Conversely, Quadrant III is reverse with speed and torque. Now the motor is “motoring” in the reverse direction, which spins backwards with the reverse torque. The Quadrant II where the motor is spinning in the forward direction, but the torque is being applied in reverse direction. Thus the torque is being used to “brake” the motor and thus the motor is now generating a power as the result. Now, Quadrant IV is exactly the opposite. The motor is spins in the reverse direction, now the torque is being applied in the forward direction. Again, now the torque is being applied to slow down the motor and change its direction so that it forwarded again. Once again, now the power is being generated by the motor. In Fig 01, when BLDC motor is operating in the first and third quadrant, the supplied voltage is now greater than the back EMF which results in forward motoring and reverse motoring modes respectively, but the direction of current flow now differs [5]. When we make the motor to operates in the second and fourth quadrant then the value of the back EMF generated by the motor should be always greater than the supplied voltage which results in forward braking and reverse braking modes respectively, now again the direction of current flow is reversed. Thus BLDC motor now initially made to rotate in clockwise direction, but we receive the speed reversal command, the control goes into the clockwise regeneration mode, which turns the rotor to the standstill position. Thus instead of waiting for the absolute standstill position, continuous energization of the main phase is attempted. This rapidly slows down now the rotor to a standstill position. Therefore, there is the necessity for determining the instant when the rotor of the machine is ideally positioned for reversal. Here Hall Effect sensors are used to sense the rotor position to determine whether the machine has reversed its direction. This seems to be an ideal moment for energizing the stator phase so that the machine can start motoring in the counter clockwise direction.

3. Model Predictive Controller

This MPC seems to be one of the most practical advanced control techniques in industrial applications. It is called as robust control method and proves to be an effective method in handling unknown dynamics. Here the future behavior is computed in accord to a model of the plant. Model predictive control is applied generally to reduce torque ripples. The effective conservation of energy is established in the proposed system as shown in Fig.02. Generally, MPC is one among the family of different type’s controllers in which there is a direct utilization of an explicit identifiable model. It is also illustrated as a class of computer control schemes that utilizes a process model for two central tasks:

- It Explicit prediction the future plant behavior
- It also Compute appropriate corrective control action required to drive the predicted output as close as possible to the required target value.

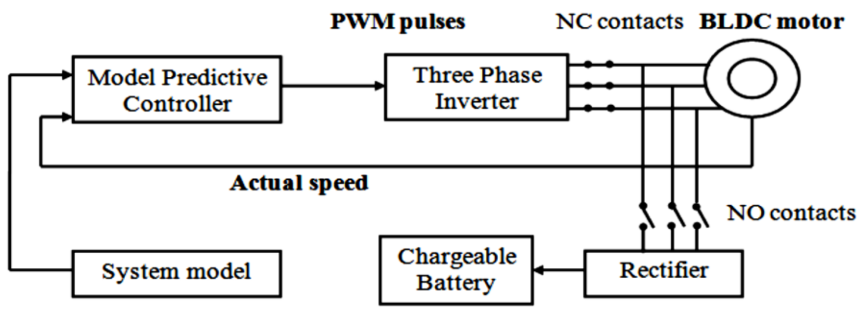

Fig.2. Block Diagram of Proposed System

It is currently used widely in industrial applications. The reason for such popularity is the ability of MPC design to yield high performance control systems capable of operating without expert intervention for long periods of time. MPC uses a dynamic model of the process in order to predict the controlled variable. The predicted controlled variable is fed back to the controller where it is used in an on-line optimization procedure, where it minimizes an appropriate cost function to determine the manipulated variable. The controller output is now implemented in real time and then the procedure is repeated every sampling time with actual process data.

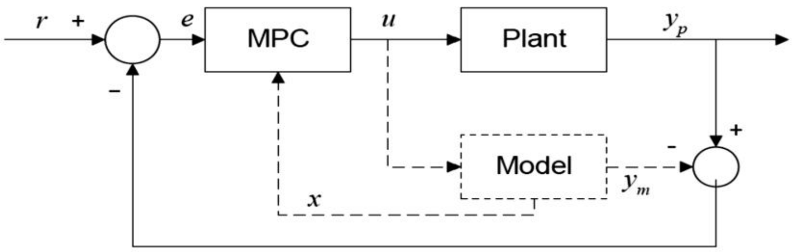

Fig.3. Block Diagram of MPC Technique

The difference between the plant measurement and the model output is also fed to the controller to eliminate steady state offset. Usually the cost function depends on the quadratic error between the future reference variable and the future controlled variable within limited time horizon. The block diagram of MPC implementation is shown in Fig 03. It is seen that the process model is used in parallel to the plant. The MPC uses a dynamic model of the process to predict the controlled variable. The predicted controlled variable is now fed back to the controller where it is used in an on-line optimization procedure, which also minimizes an appropriate cost function to determine the manipulated data. Thus the controller output is implemented in real time and then the procedure is repeated for every sampling time with actual process data. The difference between the plant measurement, y_p and the model output y_m is fed to the controller which eliminate steady state offset. Generally the cost function depends on the quadratic error between the future reference variable and the future controlled variable within limited time horizon.

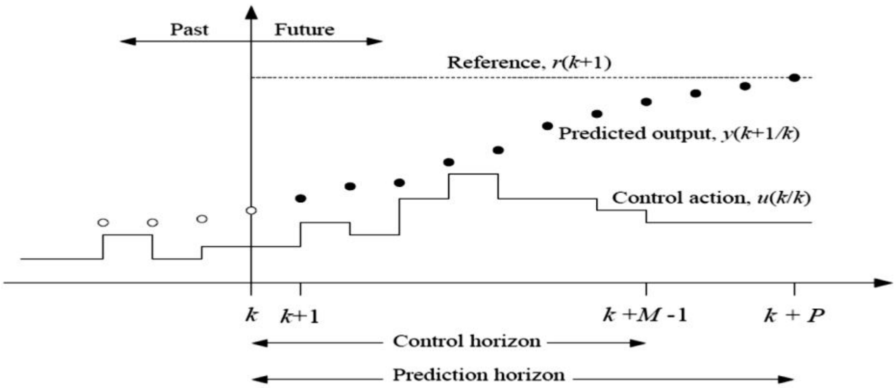

Fig.4. MPC Control Concept

Technically, the MPC has four main tuning parameters namely; the control horizon M, the prediction horizon P, the output weight matrix Γ and the input weight matrix Λ. The last two matrices are diagonal ones. Generally the sampling time has a strong impact on the control performance, however it is not used as a tuning parameter since it is often fixed based on the equipment at installation. Therefore, the total number of tuning parameters is 2+nu+ny. These parameters have profound and somewhat overlapping effect on the closed-loop performance.

4. Simulation Analysis.

The MATLAB/Simulink modeling is probably the most important phase of system control design work. Simulink modelling is a way to represent a real time world system using software, hardware or a combination of both. If the software components of the model are driven by mathematical relationships, the model can be simulated under various scenarios to verify the system.

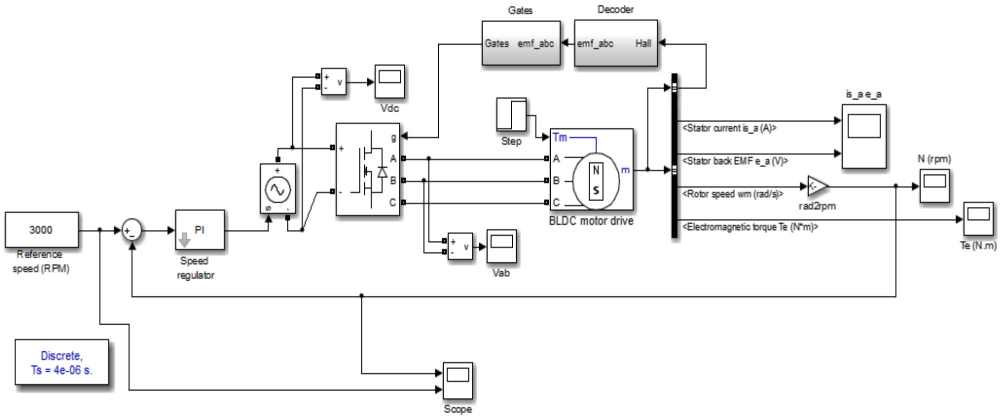

Fig.5. Simulink model of a conventional four quadrant control of BLDC motor.

The Fig.05 shows the Simulink model of a conventional four quadrant control of BLDC motor. The output voltage measures 400 volt as shown in Fig.06. The output waveform implies the presence of more current and torque ripple when simulated as shown in Fig.07 & Fig.08. The outputs are displayed taking flux, current, torque and speed on y-axis and time on x-axis.

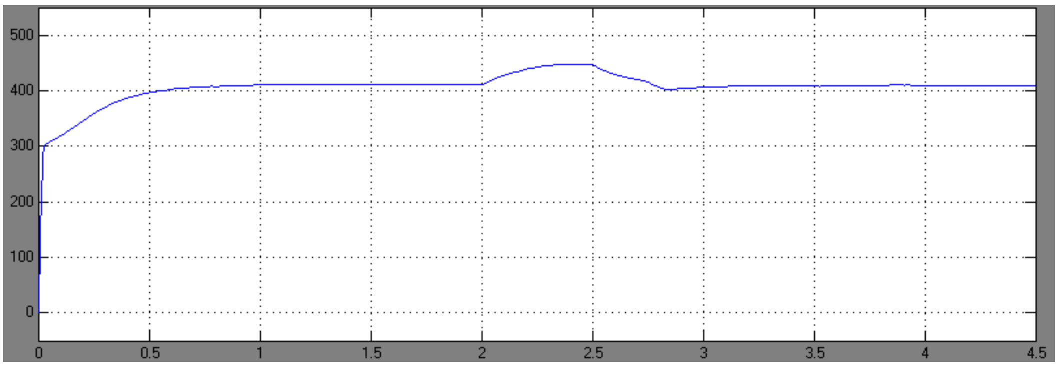

Fig.6. Output Voltage measure 400 volts

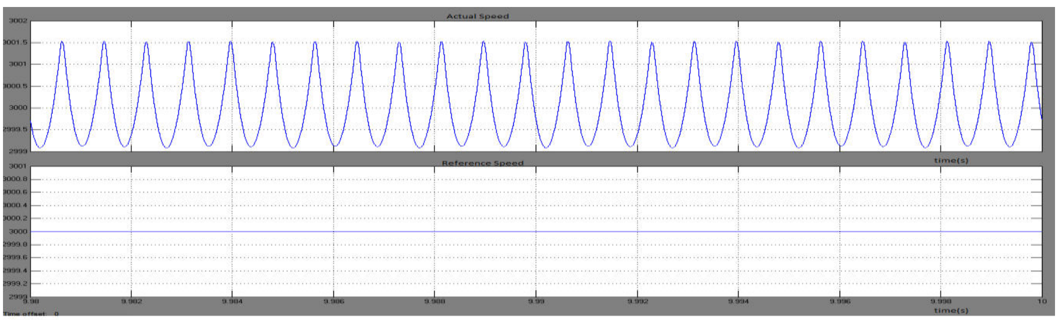

Fig.7. Speed waveform of Conventional Circuit

The Simulink model of a proposed BLDC motor with MPC controller is shown in Fig.09. Initially, DC voltage source is used as input which is fed to the motor. The rotor position sensed by Hall Sensors is fed to the MPC controller. The appropriate control signal for the gates of inverter switches are provided by the controller.

The output waveform implies that torque ripple produces is reduced during simulation compared to conventional system as shown in Fig.8 & Fig.9. At the same time, speed control which is essential in many applications is also performed. The outputs are displayed taking torque and speed on y-axis and time on x-axis.

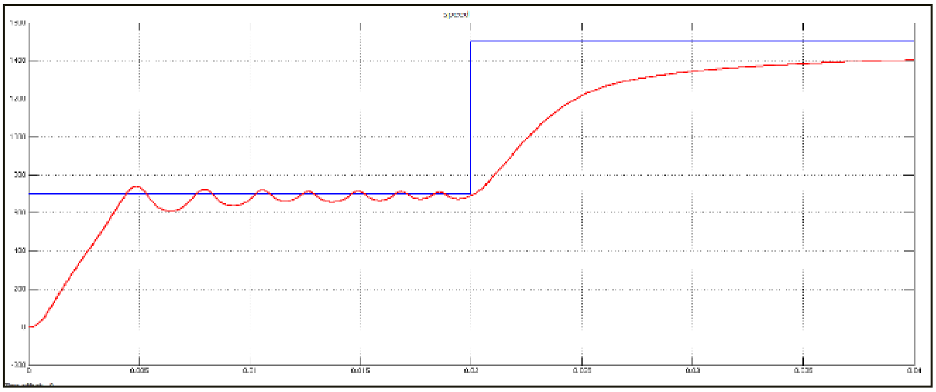

Fig.8. Output Speed Waveform of Proposed BLDC Motor Drive

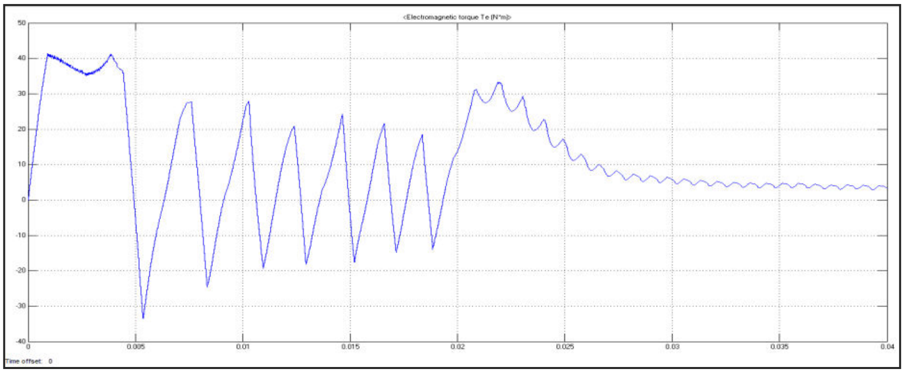

Fig.9. Output Speed Waveform of Proposed BLDC Motor Drive

5. Experimental Setup

Fig.10. Hardware Components of Proposed System

The above Fig.10. Shows the hardware board with front side for main switches and controller. The output voltage is regulated and the input current tracks the input voltage. Under full-load condition, the harmonic distortion result can be analyzed. Here AC supply is converted to DC with the help of a diode bridge rectifier. The obtained DC voltage is filtered out and is passed through the DC – DC converter. Thus obtained continuous voltage which has less voltage ripple is provided to the stator of BLDC motor according to the position of rotor. The motor terminal voltage and current are sensed and is given to controller. Based on the algorithm coded in the controller, it generates the gating pulses which are given to the converter switches through the driver circuit.

6. Conclusion.

The simulation model of BLDC motor drive system with MPC controller is obtained with MATLAB/Simulink. Thus, the obtained torque and speed characteristics are satisfactory to have reduced acoustic noise and vibrations. The Model Predictive Control algorithm used in this work provides satisfactory results which considerably reduced at time of 0.025 seconds. It also predicts the future behavior of the drive system and functions to control the system accordingly. The implement the hardware model is verified with the results obtained from MATLAB Simulink. The system model includes external disturbances such as input voltage fluctuations and mechanical disturbances to the motor. These improvements considerably increase the efficiency of the entire drive systems

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