Fuzzy Based Digital Control Strategy for Four Quadrant Three Phase BLDC Motor with Speed Stability

Murugesan.R[1], Chitra.C[2]

[1]Ranippettai Engineering College, Electrical and Electronics, T.K.Thangal, Walaja Taluk, Vellore District, India

[2]Ranippettai Engineering College, Applied Electronics, T.K.Thangal, Walaja Taluk, Vellore District, India

Abstract: ***The basic need in any speed control is to maintain the required speed even at load variations. In this paper, a novel fuzzy based speed control along with an existing PI control is added, in order to attain a fast steady state. Brushless DC (BLDC) motor drives are becoming more popular in industrial, traction applications. This makes the control of BLDC motor in all the four quadrants very vital. This paper deals with the digital control of three phase BLDC motor. The motor is controlled in all the four quadrants without any loss of power, in fact energy is conserved during the regenerative period. This digital controller with PI and fuzzy combination is very advantageous over other controllers .This control strategy is designed and simulated using matlab 7.10 with simulink model. The fuzzy rules are chosen based on the load current sensed through Hall Effect sensors.***

Keywords: BLDC motor, digital control, fuzzy, four quadrants, regenerative braking**.**

1. Introduction

Brushless DC motor has the following features such as simple in construction, high reliability, and high power density, light electromagnetic pollution, less noisy, potentially cleaner and faster. It is used extensively in servo motors and low power drive systems [1], [2]. BLDC motor uses three or more hall sensors to obtain rotor position and speed measurements. It is normally a DC motor. It has rotor and stator windings. It consists of rotor with permanent magnet and a stator with windings. . The brushes and commutator have been eliminated and the windings are connected to the control electronics. The commutator is replaced by control electronics and it energizes the proper winding. The BLDC motor is easier to start and stop due to less inertia [3]. The Brushless DC motor is driven by rectangular or trapezoidal voltage strokes coupled with the given rotor position. In order to get the maximum developed torque the voltage strokes must be aligned properly between the phases, so that the angle between the stator flux and the rotor flux is kept close to 90º. BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position or its position can also be detected without sensors. BLDC motors are used in Automotive, Aerospace, Consumer, Medical, Industrial Automation equipments and instrumentation [4].

The PI and the PID controller have been widely used as a control method of servo driving in industrial control fields. A driving specific property can be estimated well, once a control constant is properly set. But the control constant should be changed in order to maintain an optimum driving state if the driving point or the motor parameters are changed. Recently the fuzzy controller has appeared which is based on knowledge or an experience of expert rather than on a complicate mathematical modeling. The fuzzy controller works well using experimental information even if not having mathematical modeling. Moreover, the fuzzy controller is capable of real time control using fuzzy rule base.

2. Operation of BLDC Motor in Four Quadrants

2.1 Brushless DC motor

Brushless DC motor is also known as electronically commutated motor are synchronous motor that are powered by DC electric source via integrated inverter/switching power supply, which produces an AC electric signal to drive the motor. Brushless DC Motor is shown in fig.1. By using solid state switches current commutation can be controlled. The rotor position determines the commutation instants. The Hall Effect sensor is used to find the rotor shaft position which provides corresponding signals to the respective switches. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating either N or S pole is passing near the sensors[5],[7].The numbers shown around the peripheral of the motor diagram in Fig. 1 represent the sensor position code. The north pole of the rotor points to the code that is output at that rotor position. The numbers are sensor logic levels where the Most Significant bit is sensor C and the Least Significant bit is sensor A. The exact sequence of commutation can be determined by proper signals obtained from the hall sensors. These signals are decoded by combinational logic to provide the firing signals for 120° conduction on each of the three phases [6].

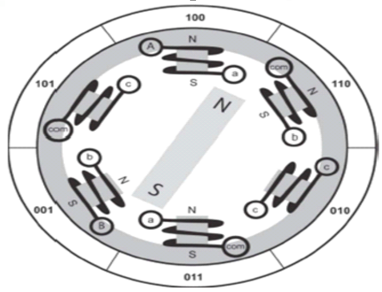

Figure 1: .BLDC motor

2.2 Operation in Four Quadrants

BLDC motor operates in all four quadrants without loss of power. There are four modes of operation namely forward and reverse motoring ,forward and reverse braking as shown in Fig. 2

BLDC motor performs motoring and generating modes. It is said to be V-I characteristics or speed-torque characteristics of BLDC motor. In first and third quadrant it acts as a motor and in second and third quardrant it acts as a generator. If the applied voltage is greater than the back emf which is forward motoring and reverse motoring modes respectively, but the direction of current flow differs. If the back emf generated by the motor should be greater than the applied voltage which is said to be the forward braking and reverse braking modes of operation respectively, here also the direction of current flow is reversed. Normally BLDC motor is made to rotate in clockwise direction, if the speed reversal command is obtained; the control goes to anticlockwise mode that is regeneration mode which brings the rotor to the standstill position. In this position continuous energisation of the main phase is attempted [8].

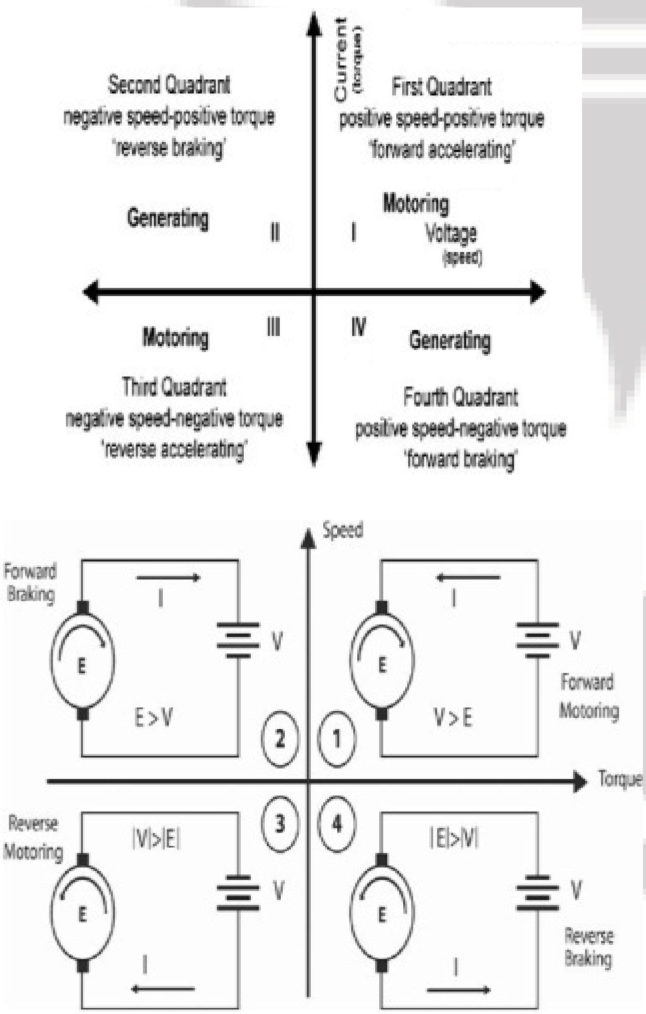

Figure 2: Four Quadrants of operation

By using Hall Effect sensors the position of the rotor can be determined. From this outputs the direction of the machine is determined whether the machine has reversed its direction. At this moment the stator phase is energized so that the machine can start motoring operation in counter clockwise direction [8]. In motoring mode electrical energy is converted in to mechanical energy and in regenerative mode motor acts as a generator so that the mechanical energy is converted in to electrical energy. The wasted energy is again converted into useful energy and it can be stored in batteries [9].

3. Proposed Work

3.1 PI Controller

The speed regulation is accomplished with PI Controller. The controller's sensitivity is increased by increasing the proportional gain of the speed controller, to have faster reaction for small speed regulation errors. This allows a better initial tracking of the speed reference by a faster reaction of the current reference issued by the speed controller. This increased sensitivity also reduces the speed overshooting. Once the desired speed is achieved. the armature current reduces faster, An increase of the integral gain will allow the motor speed to catch up with the speed reference ramp a lot faster during sampling periods. The controller will react in order to diminish the speed error integral a lot faster by producing a slightly higher accelerating torque when following an accelerating ramp. On the other hand, too high increase of the proportional and integral gains can cause instability, and the controller becoming insensitive. Too high gains may also result in saturation.

3.2 Fuzzy logic controller (FLC)

The fuzzy logic controller has three main blocks.

1. Fuzzification
2. Fuzzy inference
3. Defuzzification

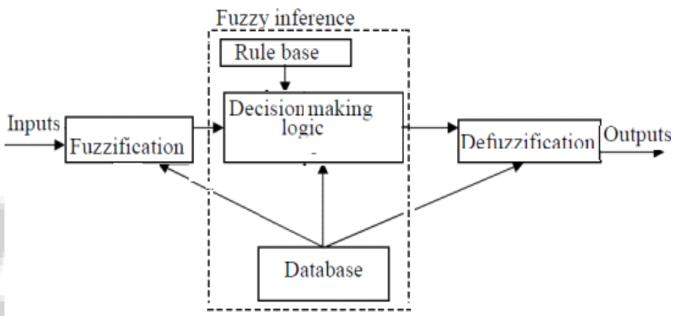

Figure 3: Fuzzy logic controller

Fuzzification: Multiple measured crisp inputs must be mapped into fuzzy membership function is called fuzzification. It performs a scale mapping that transfers the range of values of input variables into corresponding universes of discourse. It also performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

Fuzzy inference: Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The speed control of brushless DC Motor using Mamdani-style fuzzy inference system, which is composed of each one of input, and of output variable. Generally it is most important to assign the range of input and output membership function in the fuzzy inference engine. We defined input and output variables of fuzzy inference system in this paper as following.

$$\Delta\varepsilon = Cm - V \qquad (1)$$

The fuzzy input value is deviation between motor speed command Cm and hall IC signal value V. When $V_{rot}$is counter step number per one rotation, V becomes average motor speed of one rotation. The fuzzy output D changes the pulse duty D_{new} which determines motor speed so that stable speed and torque may be maintained in case of starting or load changing of motor The fuzzy rule base to control the speed of brushless DC Motor is composed of following 5 rules.

Rule 1 IF (is GN) then (D is GN)
Rule 2 IF (is SN) then (D is SN)
Rule 3 IF (is ZE) then (D is ZE)
Rule 4 IF (is SP) then (D is SP)
Rule 5 IF (is GP) then (D is GP)

Each linguistic variable presents degree of fuzzy input and output variables. GN means great negative, SN, small negative, ZE, zero, SP, small positive and GP, great positive. On starting a brushless DC Motor simulation using fuzzy inference system, the specific response character of 1400RPM speed was controlled with initial condition of Cm as 7600 and D_{old} as 1% and was experimented in a motor load condition.

Defuzzification: The output of the inference mechanism is fuzzy output variables. The fuzzy logic controller must convert its internal fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called defuzzification. The max criterion produces the point at which the membership function of fuzzy control action reaches a maximum value.

3.3 Fuzzy based speed control

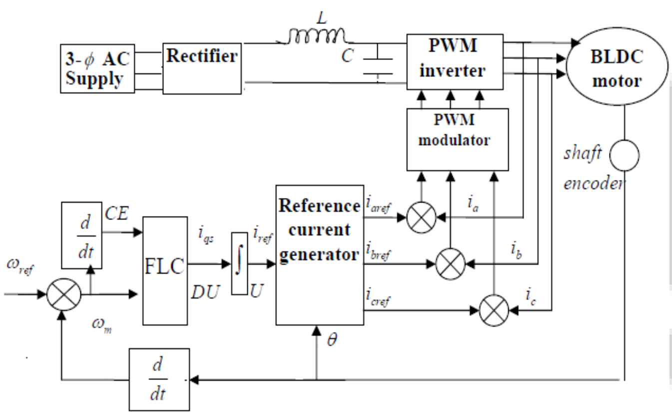

Figure 3: Fuzzy based speed control

3.4 Flow chart of fuzzy reasoning system

At first, to input value acquired from hall IC signals to the fuzzy inference system and to fuzzify the inputs value is fuzzified. Output values of fuzzy membership function to be reasoned and mapping results to be aggregated according to each rule.

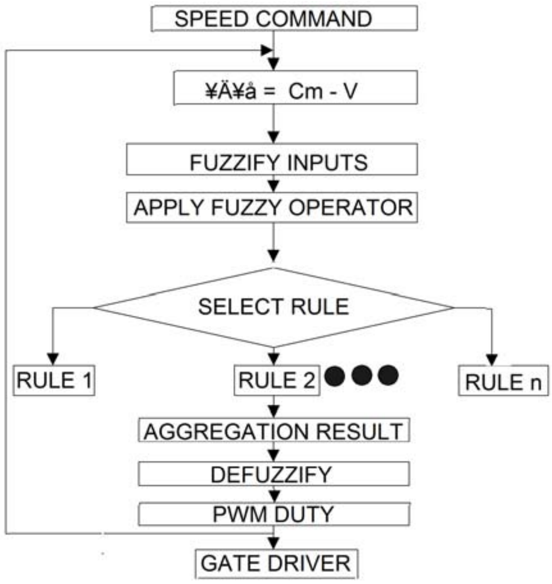

Figure 3: Flow chart for fuzzy system

4. Experimental Results

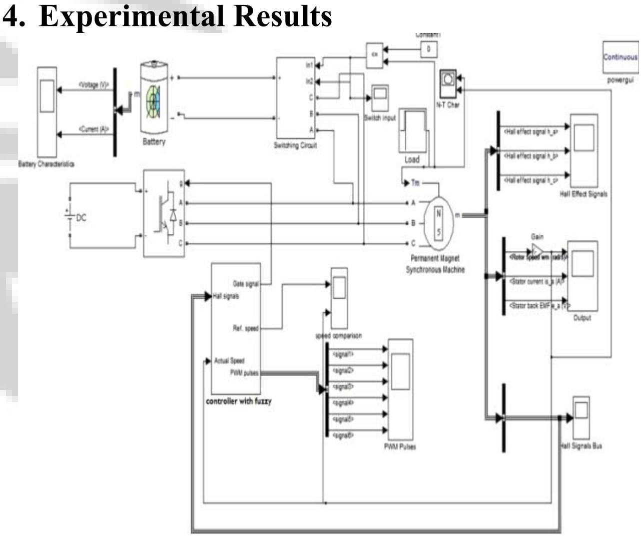

Figure 3: Simulink Model

The experimental simulink model for PI controller with fuzzy is shown in figure.7 and the simulated outputs are shown. Fig:8 shows the result of PI controller without fuzzy and fig:9, fig 10, and fig 11 shows the simulated result of stator current, rotor speed and electromagnetic torque with fuzzy logic controller.

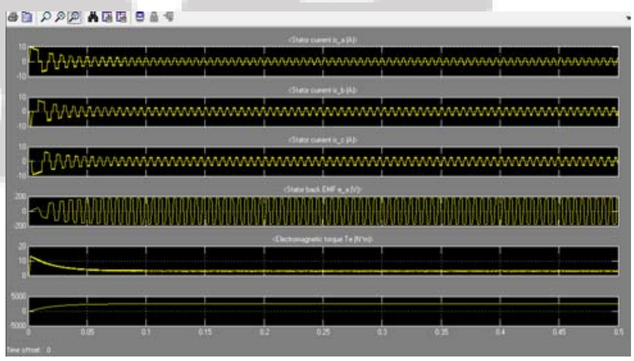

Figure 3: Output of simulink with PI controller

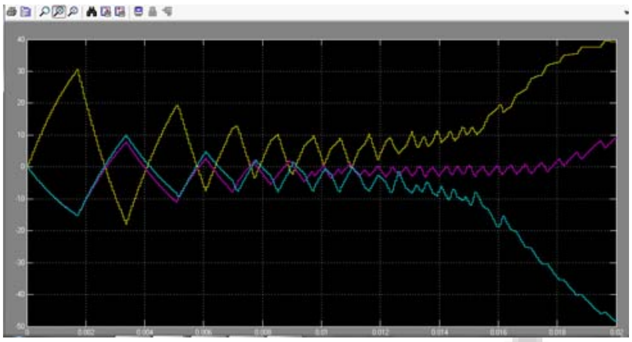

Figure 3: Stator current with fuzzy controller

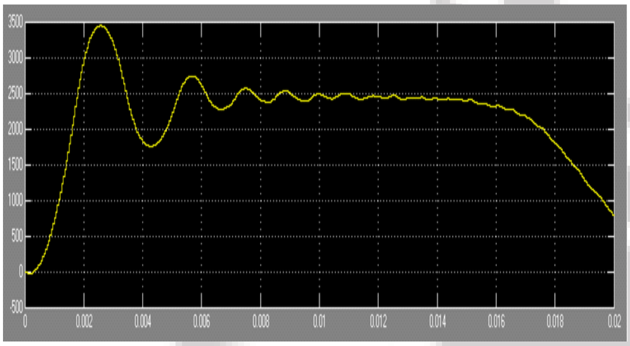

Figure 3: Rotor speed with fuzzy

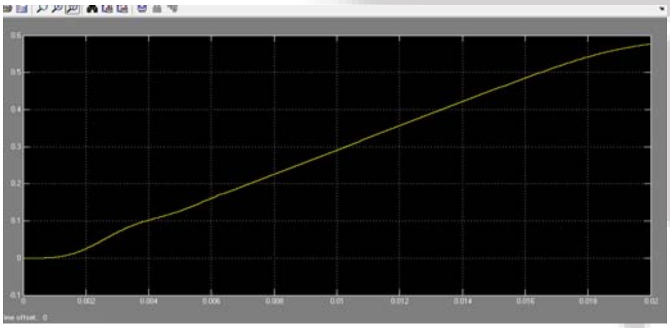

Figure 3: Electomagnetic torque with fuzzy

5. Conclusion

A fuzzy control scheme is proposed for BLDC motor to change the direction from CW to CCW and the speed control is achieved both for servo response and regulator response. The motor reverses its direction almost instantaneously, it will pass through zero, but the transition is too quick. The time taken to achieve this braking is comparatively less. The generated voltage during the regenerative mode can be returned back to the supply mains which will result in considerable saving of power. This concept may well be utilized in the rotation of spindles, embroidery machines and electric vehicles where there is frequent reversal of direction of rotation of the motor.

References

[1] W. Lee, D-K.Kim and B-I.KWON, "A novel starting method of the surface permanent magnet BLDC motors without position sensor for reciprocating compressor," IEEE Trans. Ind.Appl.,vol.44,no1,pp.85-92,Jan/Feb.2008.

[2] D-K.Kim, K.W.Lee, B-I.KWON, "commutation torque ripple reduction in a position sensorless brushless DC motor drive," IEEE Trans. Power Electron., vol.21, no.6, pp.1762-1768, Nov.2006.

[3] C. Sheeba Joice, Dr. S. R.Paranjothi, and Dr. V. Jaahar senthil Kumar, "Digital Control strategy for four quadrant operation of three phase BLDC motor with load variations," 2013, pp. 91–94, IEEE.

[4] C.W. Hung, C.-T.Lin, C.-W.Liu, and J.-Y. Yen, "A variable-sampling controller for brushless DC motor drives with low-resolution position sensors," IEEE Trans. Ind. Electron., vol. 54, no. 5, pp. 2846–2852, Oct. 2007.

[5] P. Yedamale, Microchip Technology Inc., "Brushless DC (BLDC) motor fundamentals," 2003, AN885.

[6] L. N. Elevich, "3-phase BLDC motor control with hall sensors using 56800/E digital signal controllers," AN1916, Application Note, Rev. 2.0, 11/2005.

[7] B. Singh and S. Singh, "State of the art on permanent magnet brushless DC motor drives," J.Power Electron., vol. 9, no. 1, pp. 1–17, Jan. 2009.

[8] Sathyan,M. Krishnamurthy, N.Milivojevic, and A.Emadi, "A low cost digital control scheme for brushless DC motor drives in domestic applications," in Proc. Int. Electric Machines Drives Conf., 2009, pp. 76–82.

[9] "Studies of Regenerative Braking in Electric Vehicle" M.K Yoong*, Y.H Gan, G.D Gan, C.K Leong, Z.Y Phuan, B.K Cheah. K.W Chew, Member, IEEE.

Author Profile

Chitra C completed B.E degree in Electrical and Electronics from S.A.C.S M.A.V.M.M Engineering College in 2005 and having teaching experience of two years and now studying M.E degree in Applied Electronics from Ranippettai Engineering College in 2012-2014.

Murugesan R completed B.E degree in Electrical and Electronics Engineering from Arunai Engineering College in 1998 and M.Tech degree in Dr.MGR University in 2009. He worked as lecturer from 2002 to 2007 in Ranippettai Engineering College and as Assistant Professor in the same institution from 2009 onwards.