FUZZY BASED SENSORLESS DIRECT SPEED CONTROL FOR BLDC MOTOR DRIVES

SAJLA REHMAN

Abstract— **This project presents the groundwork for a novel concept of sensor less direct speed control in BLDC motor drives. Unlike the conventional senseless speed controls consider the motor back emf and motor current. Thus feedback mechanism is minimized. Speed regulation is achieved by controlling rotational speed of stator flux linkage. The fuzzy logic control strategy has been implemented for the inverter control. This entire control concept has been implemented using SIMULINK model. The proposed control scheme will effectively reduces the torque ripple in a brushless dc motor and provides better control over the motor performance. The PI regulator is replaced with a simple comparator. The brushless dc motor is excited based on the inverter feedback. This proposal is applicable to both two-phase and three-phase conduction modes of the a brushless dc motor. In this project, principles of the proposed sensorless strategy and speed ripple calculation are described in details. The validity of this claim is verified through the simulation results.**

Index Terms— **Brushless DC motor ; PI controller ; SIMULINK ; fuzzy logic ; sensorless**.

I. INTRODUCTION

Sensorless means fewer parts and the mission of the position sensors and auxiliary decoding circuitries. The only reliable way to utilize the BLDC machine drives in harsh environments is sensorless techniques.

The brushless dc motor is well suited for automotive direct speed control today. They are inherently more reliable, more efficient, and with current electronics technology, more cost effective than the standard brush-type fuel-pump motor and controller.

Commutation sequencing can be determined in several ways. The most cost efficient in wound BLDC motors is sensing the back Electro Motive Force (EMF) of an unused phase.. This leaves the third phase available for commutation timing by sensing back EMF. Commutation timing is determined when the unused phase back EMF reaches its zero potential point. This is called the “zero crossing”. Commutation and other features can be incorporated into the application. These added features simplify the vehicle systems as well as drive overall system cost down.

II. PROPOSED FUZZY LOGIC BASED INVERTER

Manuscript received Dec 04, 2014

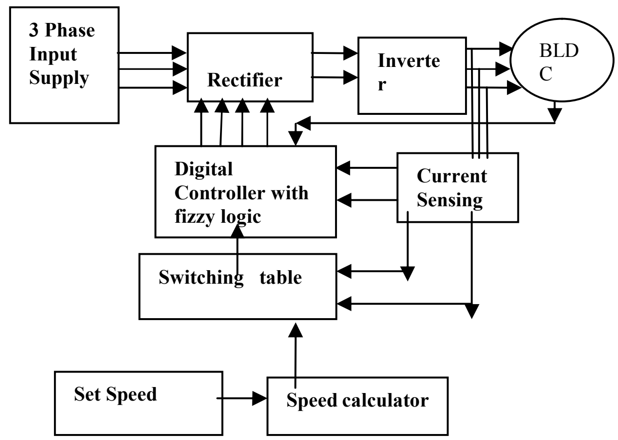


Fig.1 Block diagram of a sensorless direct speed control for brushless dc motor drives with fuzzy implementation

III. PRINCIPLES OF THE PROPOSED SENSORLESS DIRECT SPEED DRIVE

ZCP of the motor terminal is widely used in the applications, where precision is not required, like dryers, fans, and compressor and so on. Many commercial integrated circuits have been designed based on this strategy. The conventional sensorless BLDC motor speed control with detection of ZCP of the motor terminal minimization of the feedback mechanism is the main aim of this paper above mentioned in Fig 2.1 . This goal is achieved by elimination of PI controller. The proposed sensorless strategy is based on the simple rules. The PI controller is replaced with the simple comparator and a look-up table. Speed regulation is achieved by controlling rotational speed of stator flux linkage. The proposed SDSC can be utilized for both two-phase and three- phase conduction modes of BLDC motor excitations. The organization of this paper is as follow.

IV. PI CONTROLLERS

Proportional integral(PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input.

$$U(s)/ E(s) = K_p + (K_I /s) \qquad (1)$$

A PI controller (proportional-integral controller) is a special case of the PID controller in which the derivative (d) of the error is not used.

The controller output is given by

$$K_p\Delta+K_i\int\Delta dt \qquad (2)$$

Where Δ is the error or deviation of actual measured value (PV) from the Set Point (SP).

$$\Delta = SP - PV \qquad (3)$$

A PI controller can be modeled easily in software such as simulink or Xcos using a "flow chart" box involving Laplace operators:

$$C = [G(1 + Ts)]/ Ts \quad (4)$$

Where

G=Kp proportional gain

G/T=Kp integral gain

Setting a value for G is often a tradeoff between decreasing overshoot and increasing settling time.

The lack of derivative action may make the system more steady in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs. Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set point and slower to respond to perturbations than a well-tuned PID system may be. But can be realized easily in the following form:

$$OLTF = K_p\left(s + \frac{1}{T_1}\right)G_p(s) \quad (5)$$

$$CLTF = \frac{C(s)}{R(s)} = \frac{K_p\left(s+\frac{1}{T_1}\right)}{s(s^2+3s+2)+sK_p+\frac{K_p}{T_1}} \quad (6)$$

V. TUNING PI CONTROLLERS

General approach to tuning

1. Initially have no integral gain (Ti large)
2. Increase Kp until get satisfactory response
3. Start to add in integral (decreasing Ti) until the steady state error is removed in satisfactory time .(May need to reduce Kp if the combination becomes oscillatory)

VI. ANTI-WINDUP IN I & PI CONTROLLERS

Under some operating conditions non-linearity in the plant or controller can stop an integral controller from removing the steady state error. If the integrator output is not limited, then during this time the total of the integrated error will continue to build. Once the restrictions are finally removed, problems can arise because this built up "energy" must be removed before the integral control can act normal below .This can take a long time. To avoid this, anti-windup circuits are added that place limits on the integral total. These limits are usually placed on the output of the PI controller.

VII. IMPLEMENTING FUZZY LOGIC

Fuzzy logic is a problem solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded microcontrollers to large, networked, multi channel computers or workstation based data acquisition and control systems. It can be implemented in software, hardware or both. It provides a simple way for arriving at a definite conclusion based upon ambiguous, imprecise or missing input information. Fuzzy logic requires some numerical parameters in order to operate such as what is considered significant error and significant rate of change of error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them.

These are the steps to be followed

1. Define the control objectives and criteria by knowing what to control, how the system can be controlled, kind of response needed and possible system failure modes.
2. Determine the input and output relationships and choose a minimum number of variables for input to the engine.
3. Using the rule based structure of fuzzy logic, break the control problem down into a series of if x and y then z rules that define the desired system output response for given system input conditions.
4. Create membership functions that define the meaning of input and output terms used in the rules.
5. Create the necessary preprocessing and post processing routines if implementing in software, otherwise program the rules into the hardware engine.
6. Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained.

VIII. MEMBERSHIP FUNCTIONS

The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system. There are different memberships functions associated with each input and output response. Some features to note are:

Shape : triangular is common, but bell, trapezoidal and exponential have been used. More complex functions are possible but require greater computing overhead to implement.

Height or magnitude : is usually normalized to 1.

Width : is of the base of function.

Shouldering : locks height at maximum if an outer function. Shouldered functions evaluate as 1.0 past their center.

Center : points center of the member function shape.

Overlap : typically about 50% of width but can be less.

IX. OPERATIONS ON FUZZY SETS

There are many definitions for the operations of union, intersection, implies and Cartesian product. The most commonly used are:

$$\mu_{A\cap B}(X) = \min(\mu_A(X), \mu_B(X))$$

$$\mu_{A\cup B}(X) = \max(\mu_A(X), \mu_B(X))$$

$$\mu_{A\to B}(X) = \mu_{\bar{A}\cup B}(X) = \max(1-\mu_A(X), \mu_B(X))$$

$$\mu_{A\times B}(u,v) = \min(\mu_A(u), \mu_B(v)) \quad (7)$$

X. CIRCUIT DIAGRAM

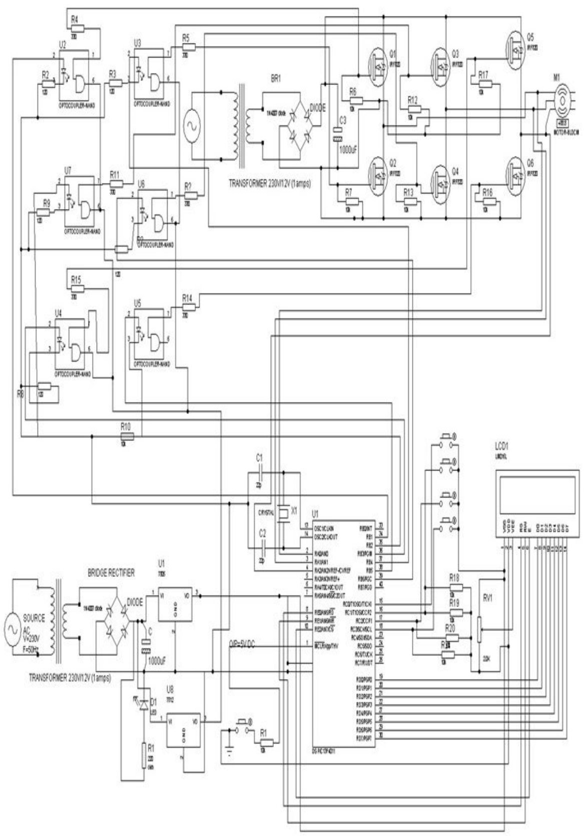


Fig 2.Circuit Diagram

XI. CIRCUIT DIAGRAM DESCRIPTION

The fig 2. shows the project circuit diagram, the dc source is applied to the power inverter, the power inverter generates the 3 phase output. The output of 3 phase power is applied to the brushless dc motor. In this project, we have to measure the BLDC motor speed without using any sensors. The BLDC motor speed measured based back emf. The back emf applied to the microcontroller controller. Externally, we have to set the speed with help of keypad as a reference speed. The speed has been calculated based on back emf, the controller is check the error output and generates the steady state error. The output of the controller is PWM pulses based on input. The speed values are corrected by the PWM pulses. The correction values are given to the PWM timer in micro controller, this controller will generate the PWM that is given to the inverter gates. Based on gate value, the inverter generates the varied output voltage, this varied output voltage is used to control the speed of motor. Here it has six MOSFETs for three pulses generation, that voltage is given to the BLDC motor.

XII. OUTPUT POWER

A power inverter will have an overall power rating expressed in watts or kilowatts. This describes the power that will be available to the device the inverter is driving and, indirectly, the power that will be needed from the dc source. Smaller popular consumer and commercial devices designed to mimic line power typically range from 150 to 3000 watts. Not all inverter applications are primarily concerned with brute power delivery, in some cases the frequency and or waveform properties are used by the follow on circuit or device .

XIII. ENHANCED QUANTIZATION

A proposal suggested in power electronics magazine utilizes two voltages as an improvement over the common commercialized technology which can only apply dc bus voltage in either directions or turn it off. The proposal adds an additional voltage to this design. Each cycle consists of sequence as: V1, V2, V3, off/pause, -V1, -V2, -V3.

XIV. MATLAB GRAPH RESULTS

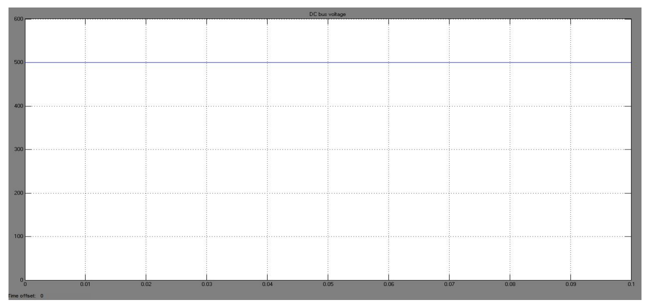
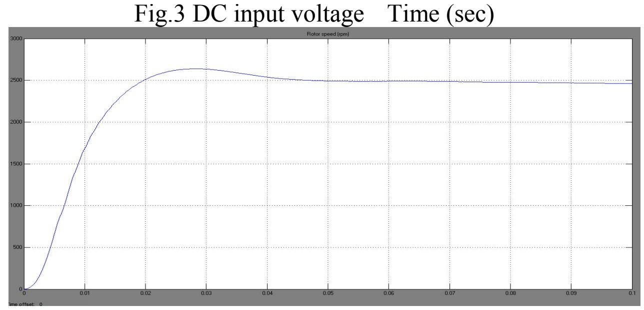
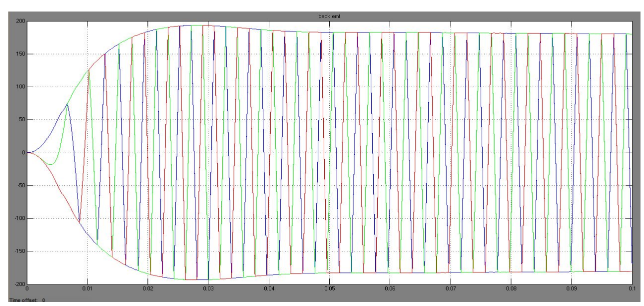


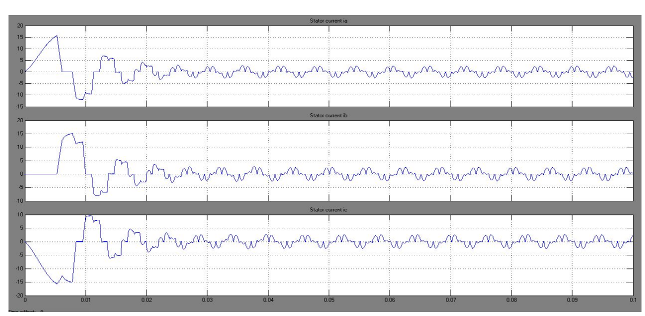
Fig.3 DC input voltage Time (sec)



Time (sec) Fig.4 motor speed



Time (sec) Fig. 5 back emf



Time (sec) Fig.6 Motor stator current

CONCLUSION

The fuzzy logic control strategy has been implemented in this project for the inverter control. This entire control concept has been implemented using digital controller. So the proposed control scheme will effectively reduces the torque ripple in a BLDC motor and provides better control over the motor performance. Thus, the feedback mechanism is minimized. Speed regulation is achieved by controlling the rotational speed of stator flux linkage. The proposal is applicable to both two-phase and three phase conduction modes. However, each phase is unexcited for part of time in two-phase conduction mode. Therefore, stator flux linkage estimation and rotor position recognitions harder than three-phase conduction mode. Simulation results show the performance of the proposal for both steady state and dynamic condition. The BLDC motor steady state speed and stator currents are verified in SIMULINK model.

REFERENCES

[1] Hsiu-PIng Wang And Yen-Tsan Liu, "Integrated Design Of Speed-Sensorless And Adaptive Speed Controller For A Brushless Dc Motor" *IEEE Trans. Ind. Applicant.*, vol. 21, No. 2, March 2006

[2] Jiancheng Fang, Haitao Li, And Bangcheng Han, "Torque Ripple Reduction In BLDC Torque Motor With Nonideal Back Emf," *IEEE Trans. Ind Appl.,* vol. 39, No. 11, November 2012.

[3] J. X. Shen and S. Iwasaki, "Sensorless Control Of Ultrahigh-Speed Pm Brushless Motor Using PLL And Third Harmonic Back Emf," *IEEE trans. Energy conv.* Vol 15, No. 2, April 2006.

[4] P. Damodharan and Krishna Vasudevan, "Sensorless Brushless DC Motor Drive Based on the Zero-Crossing Detection of Back Electromotive Force (EMF) From the Line Voltage Difference".*IEEE trans. Energy conv*. Vol. 25, No. 3, Sep 2010

[5] Salih Baris Ozturk, and Hamid A Toliyat, "Direct Torque and Indirect Flux Control of Brushless DC Motor", *IEEE/ASME transaction on mechatronics*, Vol 6, No. 2, Apri1 2011.

[6] Shao, D. Nolan, M. Teissier, and D. Swanson, "A novel microcontroller-based sensorless brushless dc (BLDC) motor drive for automotive fuel pumps," *IEEE Trans. Ind Appl.*, vol. 39, no. 6, pp. 1730-1740, Nov.lDec. 2003.

[7] Yong Liu, Z. Q. Zhu and David Howe, "Commutation-Torque-Ripple Minimization In Direct-Torque-Controlled Pm Brushless Dc Drives," *IEEE Trans. Ind. Appl.*, Vol. 43, No. 4, July/August 2007

[8] Yong Liu, Zi Qiang Zhu and David Howe, 'Instantaneous Torque Estimation In Sensorless Direct-Torque-Controlled Brushless Dc Motors," *IEEE Trans. Ind. Appl.*, Vol. 42, No. 5, September/October 2006