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Design and Performance of Cost Effective BLDC Drive Using Fuzzy Logic

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Abstract

This paper deals with the design of BLDC motor drive using fuzzy logic. More than two decades the motors play a vital role in industrial application and also in consumer appliances. The most suggested motor in above mentioned applications is BLDC Motor. It is more dominate in HVAC industry, automation, military equipment, instrumentation, CD/DVD player, home appliance such as fans and in many real time applications because of its speed and efficiency because of their operation, reliability, high torque, power factor, efficiency and low maintenance. As the need increases demand also increases linearly. This may degrade the speed of the motor which in turn affects the efficiency by lowering the torque. Decrease in speed in industrial sectors and in real time applications may lead to production loss, other unexpected loss. Increase in speed beyond the limit may even lead to human life hazards. To overcome this issue, speed must be controlled and maintained constantly. This project introduces a Fuzzy Logic Controller to control the speed of the BLDC motor by increasing the torque. Fuzzy Logic Controllers are a true extension of linear control models and is an innovative technology that enhances conventional system design with engineering expertise. The Simulink software was used to simulate the proposed scheme.

Introduction

Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realised. These motors are now known as brushless dc motors. The construction of modern brushless motors is very similar to the ac motor, known as the permanent magnet synchronous motor. The stator windings are similar to those in a polyphone ac motor, and the rotor is composed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches. The most common position/pole sensor is the Hall element, but some motors use optical sensors.Brushless Direct Current motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic fields generated by the rotor rotate at the same frequency. BLDC motors do not experience the "slip" that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations corresponding to its type; the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors.

Comparison of Conventional and Brushless Dc Motors

Although it is said that brushless dc motors and conventional dc motors are similar in their static characteristics, they actually have remarkable differences in some aspects. When we compare both motors in terms of present-day technology, a discussion of their differences rather than their similarities can be more helpful in understanding their proper applications. Table 1 compares the advantages and disadvantages of these two types of motors. When we discuss the functions of electrical motors, we should not forget the significance of windings and commutation. Commutation refers to the process which converts the input direct current to alternating current and properly distributes it to each winding in the armature. In a conventional dc motor, commutation is undertaken by brushes and commutator; in contrast, in a brushless dc motor it is done by using semiconductor devices such as transistors.

Table 1. Comparison of conventional and brushless DC motors

	Conventional motors	Brushless motors
Mechanical structure	Field magnets on the stator	Field magnets on the rotor Similar to AC synchronous motor
Distinctive features	Quick response and excellent controlability	Long-lasting Easy maintenance (usually no maintenance required)
Winding connections	Ring connection The simplest: Δ connection	The highest grade: Δ or Y-connected three-phase connection Normal: Y-connected three-phase winding with grounded neutral point, or four-phase connection The simplest: Two-phase connection
Commutation method	Mechanical contact between brushes and commutator	Electronic switching using transistors
Detecting method of rotor's position	Automatically detected by brushes	Hall element, optical encoder, etc.
Reversing method	By a reverse of terminal voltage	Rearranging logic sequencer

Proposed Methodology

A. Brushless DC Motor

A brushless motor is constructed with a permanent magnet rotor and wire wound stator poles. Electrical energy is converted to mechanical energy by the magnetic attractive forces between the permanent magnet rotor and a rotating magnetic field induced in the wound stator poles.

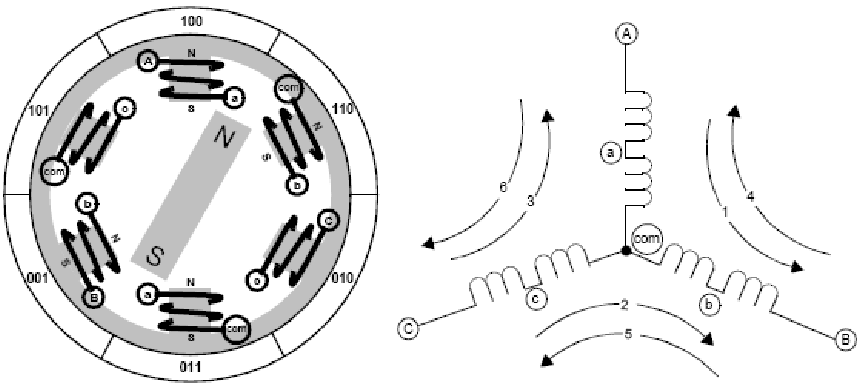

Figure 1: Simplified BLDC Motor Diagrams

In this example there are three electromagnetic circuits connected at a common point. Each electromagnetic circuit is split in the centre, thereby permitting the permanent magnet rotor to move in the middle of the induced magnetic field. Most BLDC motors have a three-phase winding topology with star connection. A motor with this topology is driven by energizing 2 phases at a time. The static alignment shown in Figure 2, is that which would be realized by creating an electric current flow from terminal A to B, noted as path 1 on the schematic in Figure 1.The rotor can be made to rotate clockwise 60 degrees from the A to B alignment by changing the current path to flow from terminal C to B, noted as path 2 on the schematic. The suggested magnetic alignment is used only for illustration purposes because it is easy to visualize. In practice, maximum torque is obtained when the permanent magnet rotor is 90 degrees away from alignment with the stator magnetic field.

The key to BLDC commutation is to sense the rotor position, then energize the phases that will produce the most amount of torque. The rotor travels 60 electrical degrees per commutation step. The appropriate stator current path is activated when the rotor is 120 degrees from alignment with the corresponding stator magnetic field, and then deactivated when the rotor is 60 degrees from alignment, at which time the next circuit is activated and the process repeats. Commutation for the rotor position, shown in Figure 1, would be at the completion of current path 2 and the beginning of current path 3 for clockwise rotation. Commutating the electrical connections through the six possible combinations, numbered 1 through 6, at precisely the right moments will pull the rotor through one electrical revolution. In the simplified motor of Figure 1, one electrical revolution is the same as one mechanical revolution. In actual practice, BLDC motors have more than one of the electrical circuits shown, wired in parallel to each other, and a corresponding multi-pole permanent magnetic rotor. For two circuits there are two electrical revolutions per mechanical revolution, so for a two circuit motor, each electrical commutation phase would cover30 degrees of mechanical rotation. levels. Assuming a supply voltage with constant frequency and without distortion, and neglecting.

Sensored Commutation

The easiest way to know the correct moment to commutate the winding currents is by means of a position sensor. Many BLDC motor manufacturers supply motors with a three-element Hall effect position sensor. Each sensor element outputs a digital high level for 180 electrical degrees of electrical rotation, and a low level for the other 180 electrical degrees. The three sensors are offset from each other by 60 electrical degrees so that each sensor output is in alignment with one of the electromagnetic circuits. A timing diagram showing the relationship between the sensor outputs and the required motor drive voltages is shown in Figure 2.

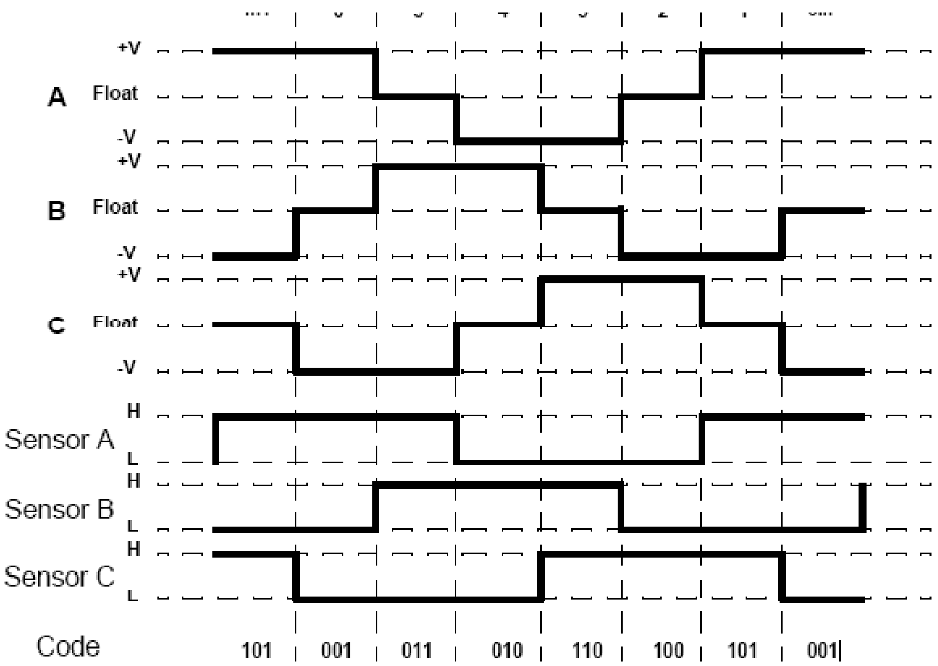

Figure 2: Sensor versus drive timing

The numbers at the top of Figure 2 correspond to the current phases shown in Figure 1. It is apparent from Figure 2 that the three sensor outputs overlap in such a way as to create six unique three-bit codes corresponding to each of the drive phases. The numbers shown around the peripheral of the motor diagram in Figure 1 represent the sensor position code. The northpole of the rotor points to the code that is output at that rotor position. The numbers are the sensor logic levels where the Most Significant bit is sensor C and the Least Significant bit is sensor A. Each drive phase consists of one motor terminal driven high, one motor terminal driven low, and one motor terminal left floating. A simplified drive circuit is shown in Figure 3. Individual drive controls for the high and low drivers permit high drive, low drive, and floating drive at each motor terminal.

One precaution that must be taken with this type of driver circuit is that both high side and low side drivers must never be activated at the same time. Pull-up and pull-down resistors must be placed at the driver inputs to ensure that the drivers are off immediately after a microcontroller RESET, when the microcontroller outputs are configured as high impedance inputs. Another precaution against both drivers being active at the same time is called dead time control. When an output transitions from the high drive state to the low drive state, the proper amount of time for the high side driver to turn off must be allowed to elapse before the low side driver is activated. Drivers take more time to turn off than to turn on, so extra time must be allowed to elapse so that both drivers are not conducting at the same time. Notice in Figure 3 that the high drive period and low drive period of each output, is separated by a floating drive phase period. This dead time is inherent to the three phase BLDC drive scenario, so special timing for dead time control is not necessary. The BLDC commutation sequence will never switch the high-side device and the low-side device in a phase, at the same time.

B Drive circuits

(1) Unipolar drive
A simple three-phase unipolar-operated motor that uses optical sensors (phototransistors) as position detectors. Three phototransistors PT1, PT2, and PT3 are placed on the end plate at 120o intervals, and are exposed to light in sequence through a revolving shutter coupled to the motor shaft.

(2) Bipolar drive
When a three-phase (brushless) motor is driven by a three-phase bridge circuit, the efficiency, which is the ratio of the mechanical output power to the electrical input power, is the highest, since in this drive an alternating current flows through each winding as an ac motor. This drive is often referred to as 'bipolar drive'. Here, 'bipolar' means that a winding is alternatively energised in the south and north poles.

B. Brushed vs. brushless motor
Brushed DC motors develop a maximum torque when stationary, linearly decreasing as velocity increases. Some limitations of brushed motors can be overcome by brushless motors; they include higher efficiency and a lower susceptibility to mechanical wear. These benefits come at the cost of potentially less rugged, more complex, and more expensive control electronics A typical Brushless motor has permanent magnets which rotate around a fixed armature, eliminating problems associated with connecting current to the moving armature. An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush/commutator system. Brushless motors offer several advantages over BLDC motors, including more torque per weight, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of Electromagnetic Interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

Brushless motor commutation can be implemented in software using a microcontroller or microprocessor computer, or may alternatively be implemented in analogue hardware, or in digital firmware using an FPGA. Commutation with electronics instead of brushes allows for greater flexibility and capabilities not available with Brushed motors, including speed limiting, "micro stepped" operation for slow and/or fine motion control, and a holding torque when stationary. The maximum power that can be applied to a brushless motor is limited almost exclusively by heat too much heat weakens the magnets and may damage the winding's insulation. When converting electricity into mechanical power, brushless motors are more efficient than brushed motors. This improvement is largely due to the brushless motor's velocity being determined by the frequency at which the electricity is switched, not the voltage. Additional gains are due to the absence of brushes, which reduces mechanical energy loss due to friction [7] The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve. Under high mechanical loads, brushless motors and high-quality brushed motors are comparable in efficiency. Environments and requirements in which manufacturers use brushless-type DC motors include maintenance-free operation, high speeds, and operation where sparking is hazardous (i.e. explosive environments) or co0uld affect electronically sensitive equipment.

Implementaion of Fuzzy Logic Contorller

Fuzzy logic is an innovative technology that enhances conventional system design with engineering expertise. Fuzzy logic is a true extension of conventional logic, and Fuzzy logic Controllers are a true extension of linear control models. A fuzzy system essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzz rules.

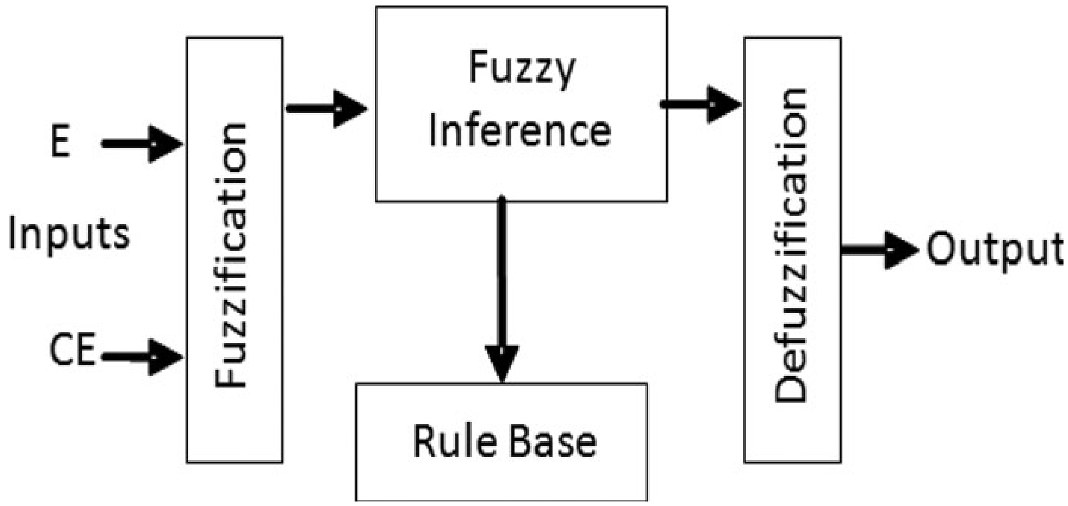

Figure 3: Block diagram of fuzzy interference

The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. The Fig.2 shows the block diagram of a fuzzy logic inference system

Step 1: Fuzzy Inputs

The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions.

Step 2: Apply Fuzzy Operators

Once the inputs have been fuzzified, we know the degree to which each part of the antecedent has been satisfied for each rule. If a given rule has more than one part, the fuzzy logical operators are applied to evaluate the composite firing strength of the rule.

Step 3: Apply the Implication Method

The implication method is defined as the shaping of the output membership functions on the basis of the firing strength of the rule. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Two commonly used methods of implication are the minimum and the product.

Step 4: Aggregate all Outputs

Aggregation is a process whereby the outputs of each rule are unified. Aggregation occurs only once for each output variable. The input to the aggregation process is the truncated output fuzzy sets returned by the implication process for each rule. The output of the aggregation process is the combined output fuzzy set.

Step 5: Defuzzify

The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a crisp value obtained by using some defuzzification method such as the centric, height, or maximum. As an example, we consider a system that determines dinner in a restaurant on the basis of the service received. We consider input membership functions with different degrees of overlap Fuzzy control has emerged one of the most active and fruitful areas of research especially in industrial processes which do not rely upon the conventional methods because of lack of quantitative data regarding the input and output relations. Fuzzy control is based on fuzzy logic, a logical system which is much closer to human thinking and natural language than traditional logical systems FLC based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy.

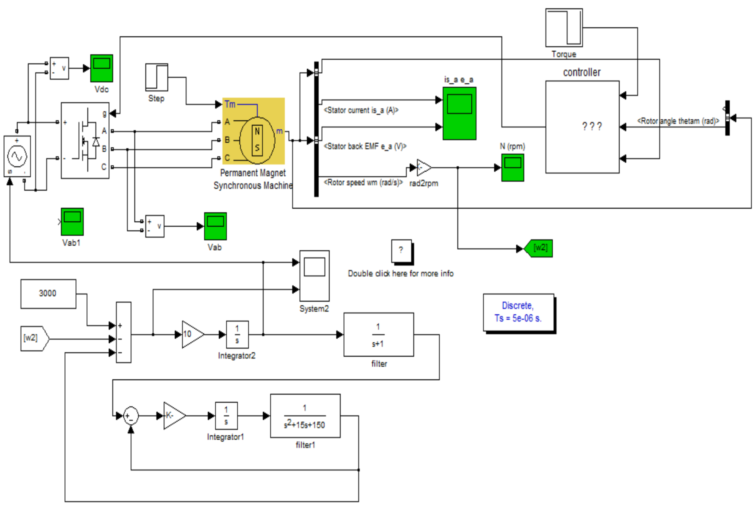

Figure 4: Speed controller and fuzzy logic controller blocks of BLDC

Software Description

Overview of Matlab
MATLAB is a multi-paradigm numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems. In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.

Overview of Simulink
Simulink, developed by MathWorks, is a data flow graphical programming language tool for modeling, simulating and analyzing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multidomain simulation and Model-Based Design. Simulink can automatically generate C source code for real-time implementation of systems. As the efficiency and flexibility of the code improves, this is becoming more widely adopted for production systems, in addition to being a popular tool for embedded system design work because of its flexibility and capacity for quick iteration. Embedded Coder creates code efficient enough for use in embedded systemsWith HDL Coder, also from MathWorks, Simulink and Stateflow can automatically generate synthesizable VHDL and Verilog. Simulink Verification and Validation enables systematic verification and validation of models through modeling style checking, requirements traceability and model coverage analysis. Simulink Design Verifier uses formal methods to identify design errors like integer overflow, division by zero and dead logic, and generates test case scenarios for model checking within the Simulink environment. The systematic testing tool TPT offers one way to perform formal test- verification and validation process to stimulate Simulink models but also during the development phase where the developer generates inputs to test the system. By the substitution of the Constant and Signal generator blocks of Simulink the stimulation becomes reproducible.

Results and Discussion

Simulation result for the three phase BLDC with modified fuzzy control unit is discussed. The MATLAB / Simulink tool is used to simulate the results. The building blocks are designed in Simulink. This tool is used to analyze the stator current, speed, electromagnetic torque, DC bus voltage and Load voltage.

The simulation results Fig 5,6 & 7 indicate that in the design of BLDC Motor stator current, rotor speed,& electromagnetic torque . It maintains a constant volatge of 300v

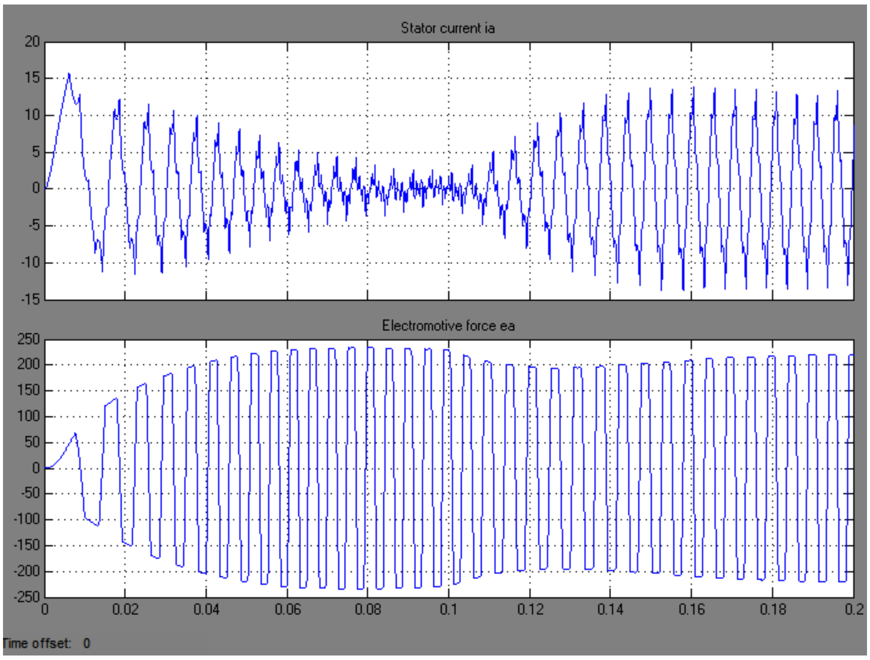

Figure 5: Simulation of stator current & electromagnetic torque

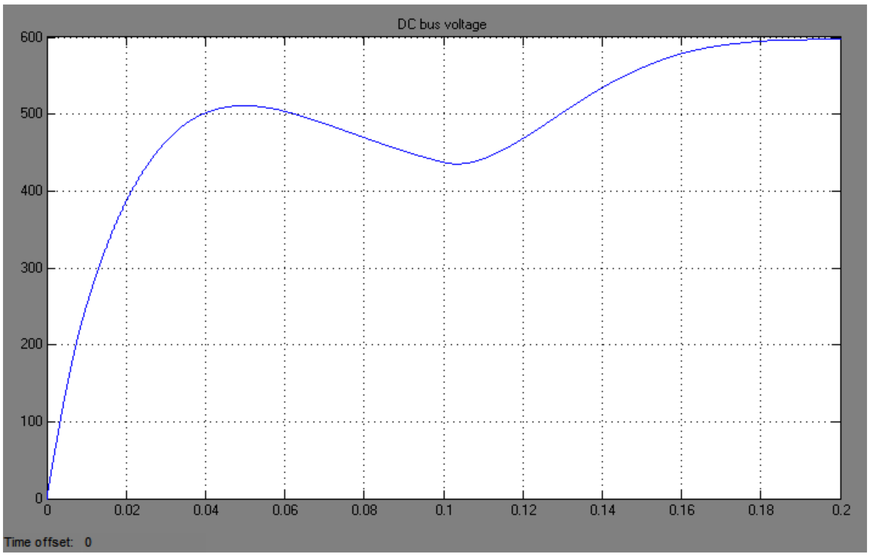

Figure 6: Simulation of DC voltage

The simulation results Fig The fig 7 shows the simulation of DC bus voltage. It maintains a constant volatge of 300v The Fig.8 shows the Simulation Result of load voltage

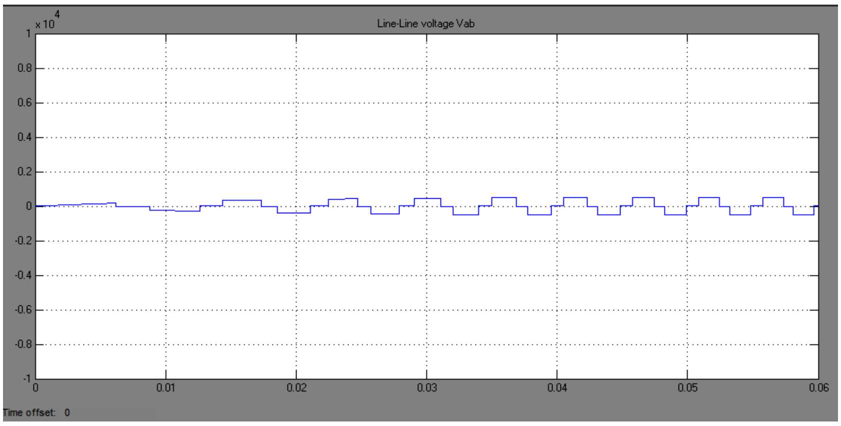

Figure 8: Simulation of load voltage

Conclusion

Early detection of abnormalities in the motor would help to avoid a costly breakdown which improves the speed, efficiency, cost and life of the motor. This project introduces a Fuzzy Logic Controller to control the speed of the BLDC motor by increasing the torque. Fuzzy Logic Controllers are a true extension of linear control models and is an innovative technology that enhances conventional system design with engineering expertise. And have made possible the application of induction motors in high performance applications The proposed motor solution designs the BLDC with fuzzy logic controller was implemented in Matlab Simulink for cost effective system and the results were obtained.

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