ANALYSIS OF BLDC MOTOR NATURE USING DIFFERENT CONTROLLER

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ABSTRACT

Brushless Direct Current (BLDC) motors, also known as permanent magnet motors find wide applications in many industries due to their higher performance, reliability and ease of control. A new generation of microcontrollers and advanced electronics has overcome the challenge of implementing required control factions, making BLDC motor more practical for a wide range of uses. The main objective of this paper is controlling speed of BLDC motor and displays its speed. The speed control of the BLDC motors is very essential. This proposed system provides a very precise and effective speed control system. The user can increase or decrease the speed as per the requirement and the motor will run at that exact speed. In this paper, we focus on the simulink modeling of BLDC using MATLAB/SIMULINK.

Keywords: BLDC Motor, PID Controller, Fuzzy Logic Controller (FLC), Particle Swarm Optimization (PSO), Trapezoidal Commutation, PI Fuzzy Controller.

INTRODUCTION

The control systems are the integral and major part of the modern society. They consist of subsystems and processes which are assembled for controlling purposes of many processes in modern industry. For domestic or industrial works motion control is required. The systems that are employed for such controls are called drives. In electric drives use of various sensors and control algorithm is done to control the speed of motor. The open loop systems consist of input transducers that convert the signal in desired electrical form used by controller. The controller further drives a plant or a process. The input is also called reference and output is a control variable. The disadvantages of open loop system are sensitive to disturbances and inability to correct for those disturbances. This may be removed by using closed loop systems. The closed loop systems overcome the problem for disturbances by measuring output response and feeding that through feedback system and comparing them at summing junctions. If there is any difference in the two responses, the system drives the plant to make a correction. If no such difference is found, it does not drive the plant since plant response is already a desired response. The close loop systems have major advantage of accurate control than open loop system. The effect of disturbances, noise and environmental factors can be made ineffective. Transient and steady state response can be improved with great flexibility by redesigning the controller. [10]

The DC motors are expensive due to brushes and commutators. DC motors have low torque to volume and torque to inertia ratios. On other hand the characteristics are quite linear and are easy to control. DC motors are generally used for high power application like in machine tools and robotics. It is interesting to know that almost half of industries use PID or modified PID schemes. Because PID can be adjusted on site, many types of tuning rules have been proposed. The mathematical model of plant suggests that PID control can give best results. In the field of control systems, it is well known that basic and modified PID systems have proves their usefulness in providing satisfactory response although in many situations they may not provide optimal control.

To achieve that optimal control intelligent fuzzy controllers can be used. Fuzzy logic control (FLC) is one of the successful applications of fuzzy set theory introduced by L.A. Zadeh in 1973. Since then FLC has been an extremely active and fruitful research area with many industrial applications. FLC has evolved as an alternative or complementary to various control strategies in area of engineering. Fuzzy logic provides non linear controllers which are capable of performing different complex non linear control actions, even for uncertain nonlinear systems. Unlike conventional controllers, for designing a FLC it is not necessary to have a precise knowledge of system model such as poles and zeros of the system transfer function. Imitating the human way of learning, the tracking error and rate of change of error of inputs are required for the design of fuzzy inference system. [56]

Modern heuristic optimization techniques such as genetical algorithm and neural networks annealing are much into the work by many researchers due to their ability to find an optimal accepted solution. One of the modern heuristic optimization paradigms is the particle swarm optimization. PSO is a kind of evolutionary algorithm based on a population of individuals and motivated by the simulation of social behavior instead of the survival of the fittest individual. It is a population-based evolutionary algorithm. Similar to the other population-based evolutionary algorithms PSO is initialized with a population of random solutions. Unlike the most of the evolutionary algorithm solution PSO also works with a randomized velocity, and the potential solutions called particles which are flown through the problem space. The difference between PSO and the other evolutionary algorithms is that PSO opts the path of cooperation over competition. On other hand algorithms commonly use some form of decimation, survival of the fittest. In contrast, the PSO population is stable and individuals are not destroyed or created. Individuals are influenced by the best performance of their neighbors. Individuals eventually converge on optimal points in the problem domain. [54] PSO does not have genetic operators like between individuals and mutation, and other individuals never substitute particles during the process of implementation. The PSO refines its search by attracting the particles to positions with good solutions. While compared with genetic algorithms, the information sharing mechanism in PSO is totally different. In genetical algorithm chromosomes share information with each other. The whole population moves like a one group towards an optimal area. In PSO only the G_{best} i.e. global best or P_{best} i.e. fitness value gives the information. In PSO, all the particles tend to converge to the best solution quickly as compared with genetical algorithm. [8]

BLDC MOTORS

DC motors are motors which run on direct current either from a DC supply or a battery. Direct current defines electricity at a constant voltage. When a battery or DC supply is connected to DC motor leads. The motor converts electrical energy into mechanical energy. A DC motor relies on the fact that magnet poles repels and unlike magnetic poles attracts each other. A coil of wire with a current running throughout it generates an electromagnetic field associated with the center of the coil. By switching the current on or off in a coil its magnetic field can be switched on or off or by switching the direction of the current in the coil the direction of the generated magnetic field can be switched 180°. DC motor typically has a stationary set of magnets in the stator and an armature with a series of two or more windings of wire wrap in insulated stack slots just about iron pole pieces with the ends of the wires terminating on a commutator. The armature includes the escalating bearings that keep it in the center of the motor and the power shaft of the motor and the commutator connections. The winding in the armature continue to loop all the way around the armature and uses either single or parallel conductors (wires), and can circle numerous times around the stack teeth. The total amount of current sent to the coil, the coil's size and what it's wrapped around state the strength of the electromagnetic field created. The string of turning a particular coil on or off dictate what direction the effective electromagnetic fields are pointed. By turning on and off coils in sequence a rotating magnetic field can be created. These rotating magnetic fields intermingle with the magnetic fields of the magnets (permanent or electromagnets) in the stationary part of the motor (stator) to create a force on the armature which causes it to rotate. In some DC motor designs the stator fields use electromagnets to create their magnetic fields which allow greater control over the motor. At high power levels DC motors are cooled using forced air. The commutator allows each armature coil to be activated in turn. The current in the coil is typically supplied via two brushes that make moving contact with the commutator. Now, some brushless DC motors have electronics that switch the DC current to each coil on and off and have no brushes to wear out or create sparks. [11]

DC Motors

DC motors were the first type of motor widely used and the systems (motors and drive) initial costs tend to be typically less than AC systems for low power units. However, with a higher power, the overall maintenance costs increase and would need to be taken into consideration. The DC Motors speed can be controlled by varying the supply voltage, they are available in a wide range of voltages, the most popular types are 12 & 24V.

The two common types are:

1) Brushed

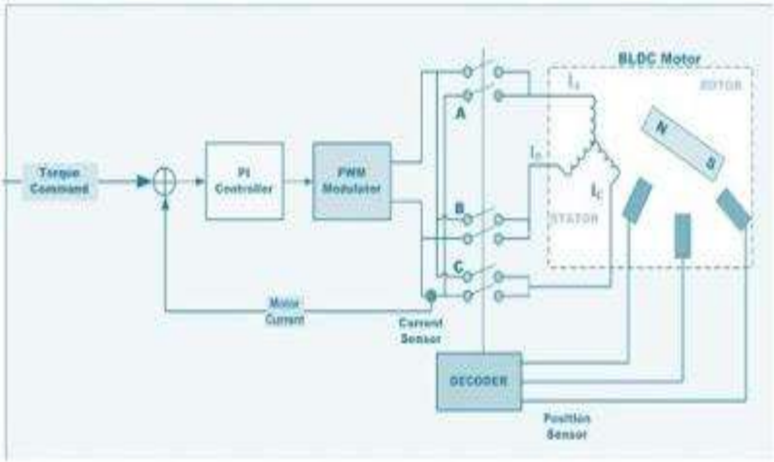
These are the more traditional type of motor and are typically used in cost-sensitive applications, where the control system is relatively simple, such as in consumer applications and more basic industrial equipment, these type of motors can be broken down as:Series Wound ,Shunt Wound, Compound Wound, Permanent Magnet.

2) Brushless

Brushless motors alleviate some of the issues associated with the more common brushed motors (short life span for high use applications) and are mechanically much simpler in design (not having brushes). The motor controller uses Hall Effect sensors to detect the rotor's position, using this the controller can accurately control the motor via current in the rotor coils) to regulate the speed. The advantages of this technology is a long life, little maintenance and high efficiency (85-90%), whereas the disadvantages are higher initial costs and more complicated controllers. These types of motors are generally used in speed and positional control with applications where reliability and ruggedness are required, such as fans, pumps and compressors. Brushless motors are also available with a feedback device which allows the control of the Speed, Torque and Position of the motor and the intelligent electronics control all three so, if more torque is required to accelerate quickly to a certain speed then more current is delivered, these are known as **Brushless Servo Motors**.

3) Trapezoidal Commutation of BLDC Motor:

One of the simplest methods of control for dc brushless motors uses what is termed Trapezoidal commutation. In this scheme, current is controlled through motor terminals one pair at a time, with the third motor terminal always electrically disconnected from the source of power.



Three Hall devices embedded in the motor are usually used to provide digital signals which measure rotor position within 60 degree sectors and provide this information to the motor controller. Because at any time, the currents in two of the windings are equal in magnitude and the third is zero, this method can only produce current space vectors having one of six different directions. As the motor turns, the current to the motor terminals is electrically switched (commutated) every 60 degrees of rotation so that the current space vector is always within the nearest 30 degrees of the quadrature direction. The current waveform for each winding is therefore a staircase from zero, to positive current, to zero, and then to negative current. This produces a current space vector that approximates smooth rotation as it steps among six distinct directions as the rotor turns.In motor applications such as air conditioners and refrigerators use of Hall-Effect sensors is not a viable option. Back-EMF sensors that sense the back EMF in the unconnected winding can be used to achieve the same results.The trapezoidal-current drive systems are popular because of the simplicity of their control circuits but suffer from a torque ripple problem during commutation.

4) Sinusoidal Commutation for BDLC Motors:

Trapezoidal commutation is inadequate to provide smooth and precise motor control of brushless dc motors, particularly at low speeds. Sinusoidal commutation solves this problem.

This is because the torque produced in a three phase brushless motor (with a sine wave back-EMF) is defined by the following equation:

Shaft Torque = Kt [I_RSin(δ) + I_Y Sin(δ +120) + I_B Sin(δ o+240)]

where:

δ is the electrical angle of the shaft,

Kt is the torque constant of the motor and

I_R, $I_Y$and I_B are the phase currents.

Assuming phase currents sinusoidal: I_R = I_0Sinδ; I_Y = I_0Sin (δ +120); I_B = I0Sin (δ +240)

Therefore,

Shaft Torque = 1.5I_0xKt

Sinusoidal commutated brushless motor controllers attempt to drive the three motor windings with three currents that vary smoothly and sinusoidally as the motor turns. The relative phases of these currents are chosen so that they should result in a smoothly rotating current space vector that is always in the quadrature direction with respect to the rotor and has constant magnitude. This eliminates the torque ripple and commutation spikes associated with trapezoidal commutation.

Sinusoidal commutation results in smoothness of control that is generally unachievable with trapezoidal commutation. However, while it is very effective at low motor speeds, it tends to fall apart at high motor speeds. This is because as speed goes up the current loop controllers must track a sinusoidal signal of increasing frequency. At the same time they must overcome the motor back-EMF that also increases in amplitude and frequency as speed goes up.

This degradation continues as speed increases. At some point motor current phase shift crosses through 90 degrees. When this happens torque is reduced to zero. With sinusoidal commutation, speeds above this point result in negative torque and are therefore not achievable.

COMPONENTS AND TOOLS

MATLAB

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming.MATLAB is developed by MathWorks.It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and FORTRAN; analyze data; develop algorithms; and create models and applications.It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods.

SIMULINK

Simulink is a graphical extension to MATLAB for modeling and simulation of systems. One of the main advantages of Simulink is the ability to model a nonlinear system, which a transfer function is unable to do. Another advantage of Simulink is the ability to take on initial conditions. When a transfer function is built, the initial conditions are assumed to be zero.

In Simulink, systems are drawn on screen as block diagrams. Many elements of block diagrams are available, such as transfer functions, summing junctions, etc., as well as virtual input and output devices such as function generators and oscilloscopes. Simulink is integrated with MATLAB and data can be easily transfered between the programs. In these tutorials, we will apply Simulink to the examples from the MATLAB tutorials to model the systems, build controllers, and simulate the systems. Simulink is supported on Unix, Macintosh, and Windows environments; and is included in the student version of MATLAB for personal computers. For more information on Simulink, please visit the MathWorks home.The idea behind these tutorials is that you can view them in one window while running Simulink in another window. System model files can be downloaded from the tutorials and opened in Simulink. You will modify and extend these system while learning to use Simulink for system modeling, control, and simulation. Do not confuse the windows, icons, and menus in the tutorials for your actual Simulink windows. Most images in these tutorials are not live - they simply display what you should see in your own Simulink windows. All Simulink operations should be done in your Simulink windows.

Types of controller :

Pi Controller

1. P Controller
2. PID Controller
3. Fuzzy Controller
4. PID Fuzzy Controller
5. PI Fuzzy Controller

PID CONTROLLER

Proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism which is used in industrial control systems. A PID controller calculates error value as the difference between measured process variable and desired set point. The controller tries to reduce the error by adjusting the process through the use of a manipulated variable.The PID controller algorithm has three different parameters, i.e. the proportional, integral and derivative values, denoted as P, I, and D. These values can be interpreted in terms of time. P depends on the present error, I on accumulation of past errors and D is prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. In the absence of understanding of the fundamentalprocess, a PID controller has been considered as best controller. By tuning the three parameters of the PID controller using algorithm, the controller can give control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set

point, and the degree of system

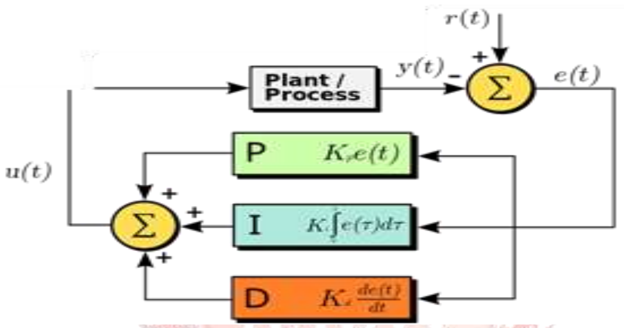


Figure 4.1 Block diagram of generalized PID controller [40]

FUZZY CONTROLLER

Fuzzy controllers are very simple practically. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs like switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. The output stage converts the combined result back into a specific control output value. Rules can be solved in parallel in hardware, or sequentially in software. The results of all the rules that have fired are "defuzzified" to a crisp value by one of several methods. Defuzzification is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. It is typically needed in fuzzy control systems. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in terms of membership in fuzzy sets. Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value. [13]

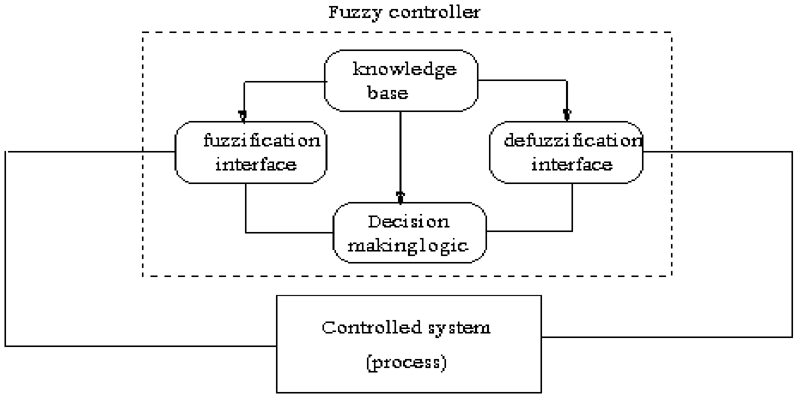


Figure 4.2 Block diagram representation for Fuzzy controller. [20]

The general process is as follows

Document the system's operational specifications and inputs and outputs.

- Document the fuzzy sets for the inputs.
- Document the rule set.
- Determine the defuzzification method.
- Run through test suite to validate system, adjust details as required.
- Complete document and release to production.

PID Fuzzy Controller

Proportional integral derivative (PID) control is a well established way of driving a system towards a target position or level. It's practically ubiquitous as a means of controlling temperature, and finds application in myriad chemical and scientific processes as well as automation. PID control is however not without problems. It can yield less than ideal results in situations where the target value changes, whether as a step function or as part of a "ramp & soak" profile.In an effort to improve performance, some instrumentation manufacturers are exploring the value of using "fuzzy logic" for process control. This OMEGA Engineering White Paper explores both the weaknesses of PID systems and the potential benefits of fuzzy logic controllers, with particular reference to issues in temperature control. Individual sections address:

- Introduction to fuzzy logic for control
- PID plus adaptive fuzzy logic
- Applications

Introduction to Fuzzy Logic Control

PID Plus Adaptive Fuzzy Logic

Tuning of PID loops depends on heuristics yet often ends up being sub-optimal. Fuzzy logic provides an alternative to approaches such as Ziegler Nichols, and a growing body of research suggests it yields superior results. Thus it would seem an ideal way to control many complex processes is with a PID controller tuned with fuzzy logic.

APPLICATIONS

Heat treatment of metals. Currently there are many applications of Fuzzy Logic utilized by common household devices, products which most people are familiar with. The benefit of a Fuzzy Logic controller becomes transparent to the user of consumer devices since the Fuzzy Module or function is embedded within the product. The advantage of this approach takes the need for the operator to understand the theory of fuzzy operation away. Operation only requires the application of common knowledge to the standard parameters. A few products which have benefited from the implementation of Fuzzy Logic are: camcorders with automatic compensation for operator injected noise such as shaking and moving; elevators with decreased wait time, making intelligent floor decisions and minimizing travel and power consumption; anti lock braking systems with quick reacting independent wheel decisions based on current and acquired knowledge; television with automatic color, brightness, and acoustic control based on signal and environmental conditions; and finally, most importantly to this article, single loop temperature and process controls.Unless open-loop control is acceptable, almost every process control application would benefit from PID control. In terms of temperature control, good examples are: Heat treatment of metals. “Ramp & Soak” sequences need precise control to ensure desired metallurgical properties are achieved.

- Drying/evaporating solvents from painted surfaces. Over-temperature conditions can damage substrates while low temperatures can result in product damage and poor appearance.
- Curing rubber. Precise temperature control ensures complete cure is achieved without adversely affecting material properties.
- Baking. Commercial ovens must follow tightly prescribed heating and cooling sequences to ensure the necessary reactions take place.
- Ceramics. Continuous kilns must deliver high levels of heat yet are subject to varying thermal loads. This makes them an ideal application for PID control.

In addition, many scientific and chemical processes rely on careful and accurate temperature control using fuzzy logic.

Key Takeaways

Commercial baking facility.Closed-loop control attempts to keep the actual output from a process as close to the target or setpoint output as possible.PID control is an established method of providing such control, but requires tuning for optimal performance. Such tuning is complex and difficult so heuristic techniques, such as the Ziegler Nichols method, are usually employed.Processes requiring step change or “Ramp & Soak” control are especially difficult to handle through conventional PID techniques. To address this, controller manufacturers like OMEGA are incorporating auto tuning capabilities to fuzzy logic controllers. Advanced computational techniques are used to help optimize PID loops, and provide improved levels of process control.

PI FUZZY CONTROLLER

Attempts are being made to enhance the drive performance by intelligent control using fuzzy logic (FL) and neural network techniques. One of the frequently discussed applications of artificial intelligence in control is the replacement of a standard proportional plus integral (PI) speed controller with an FL or artificial neural network (ANN) speed controller. Regardless of all the work, it appears that a thorough comparison of the drive behavior under PI, FL, and ANN speed control is necessary. This article attempts to compare PI, fuzzy, and ANN controllers that are implemented in an embedded system for closed-loop speed control of DC drive fed by a buck-type DC–DC power converter. The PI controller is designed based on the small signal modeling of the system. The PI-like fuzzy controller structure is considered for comparison. Two ANN controllers are designed. One controller uses training data obtained from the simulation of a fuzzy controller and the other uses training data from the simulation of a PI controller. The performance of the controllers is studied for a variety of operating conditions, such as step change in speed command and step change in load torque. The parameters selected for the comparison are the steady-state error and the rise time of the response. It is shown that ANN speed controllers provide a superior speed response in terms of rise time and the steady-state error compared to PI and FL controllers. This advantage arises from the fact that the neural network has the property of generalization and the control surface of the neural controller is smooth. The designed neural network controller is simple, with three neurons only, and so it is best suited for embedded system implementation. It is also found that the ANN controller trained with the training data from a PI controller has a better response compared to the ANN controller trained with data from a fuzzy controller. A **proportional–integral–derivative controller** (**PID controller** or **three-term controller**) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name.

In practical terms it automatically applies an accurate and responsive correction to a control function. An everyday example is the cruise control on a car, where ascending a hill would lower speed if only constant engine power were applied. The controller's PID algorithm restores the measured speed to the desired speed with minimal delay and overshoot by increasing the power output of the engine.

The first theoretical analysis and practical application was in the field of automatic steering systems for ships, developed from the early 1920s onwards. It was then used for automatic process control in the manufacturing industry, where it was widely implemented in at first pneumatic, and then electronic controllers. Today the PID concept is used universally in applications requiring accurate and optimized automatic control.

Continuous control, before PID controllers were fully understood and implemented, has one of its origins in the centrifugal governor, which uses rotating weights to control a process. This had been invented by Christiaan Huygens in the 17th century to regulate the gap between millstones in windmills depending on the speed of rotation, and thereby compensate for the variable speed of grain feed.[2][3]

With the invention of the low-pressure stationary steam engine there was a need for automatic speed control, and James Watt's self-designed "conical pendulum" governor, a set of revolving steel balls attached to a vertical spindle by link arms, came to be an industry standard. This was based on the millstone-gap control concept.[4]

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