

SIMULINK MODEL OF ADAPATIVE FUZZY PID CONTROLLER BASED BLDC MOTOR DRIVES

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Abstract- To save the energy consumption of various devices green and eco-friendly electronics are developed. This lead to the development of Brushless DC motor (BLDCM). Brush less dc motor is defined as a permanent synchronous machine with rotor position feedback. Brushless dc motors are now a days more popular in industrial and traction applications. The brushless dc motor drive consists of four main parts- power converter, permanent magnet- synchronous machine (PMSM), sensors and control algorithm. Many varieties of control techniques such as PI, PID and fuzzy logic controller have been introduced for the speed control of the BLDC motor. In this paper an adaptive fuzzy PID controller which implies parallel combination of fuzzy PI and fuzzy PD is used for speed control of BLDC motor, which is found to be more efficient in tracking the speed under conditions of external disturbances and allows regenerative braking without any loss in power.

Keywords- BLDC motor; regenerative braking; adaptive fuzzy controller; back EMF; fuzzy PI; fuzzy PD

INTRODUCTION

In early 19th century permanent magnet excitation system was used for first time in electrical machines. The performance of this machine was very poor due to poor quality of hard magnetic material make this less usable. After the invention of alnico invigorated the use of permanent magnet excitation system increases. Rare earth permanent magnets improve the power density and dynamic performance of the machine. Induction motors are most popular machine in the 20th century due to its simple construction, less price, reasonable reliability and low maintenance. Due to small air gap, lower efficiency and low power factor than synchronous machine make synchronous machine prevalent in industrial applications. Due to high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless dc (BLDC) motor, best choice for high performance applications. Due to the absence of brushes and commutator there is no problem of mechanical wear of the moving parts. BLDC has several advantages over other machine types. Most notably they require lower maintenance due to the elimination of the mechanical commutator. It also has high power density compared to induction machines, They have lower inertia, faster dynamic response to reference commands, better heat dissipation property and ability to operate at high speeds make them superior to the conventional dc machine

PRINCIPLE OF OPERATION

The transverse section of BLDC motor is shown in fig.1.The brushless dc motor is actually a permanent magnet ac motor whose torque-current characteristics mimic the dc motor.Instead of commutating the armature current using brushes, electronic commutation is used.

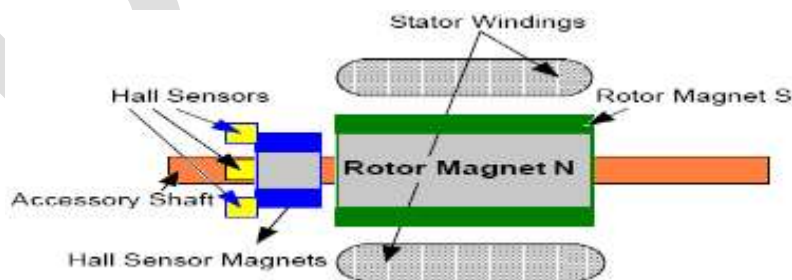


Fig.1.Transverse Section of BLDC Motor

The stators windings are star connected and are fed with current pulses of 120 degree duration. The polarity of current pulses is same as that of the induced voltage. Since the air gap flux is constant, the voltage induced is proportional to the speed of the rotor. The Hall Effect sensors mounted at 60 degree intervals and aligned suitably with the stator winding are used to detect the rotor positions. The current polarity reversal is performed by the inverter switches switched in synchronization with rotor position. During each 60 degree interval, current enters one phase and comes out of another phase.

Power supplied to the motor in each interval is given as,

$$P = 2ke \tag{1}$$

Torque developed by the motor

$$T = \frac{p}{w} = 2keId = KtId \tag{2}$$

where K_e is the backemf constant and K_t is the torque constant. Torque is produced by the interaction between magnetic fields generated by the stator coils and permanent magnets. Ideally peak torque occurs when these two fields are at 90 degree to each other. Regenerative braking is obtained by reversing the phase currents.

CIRCUIT DESCRIPTION

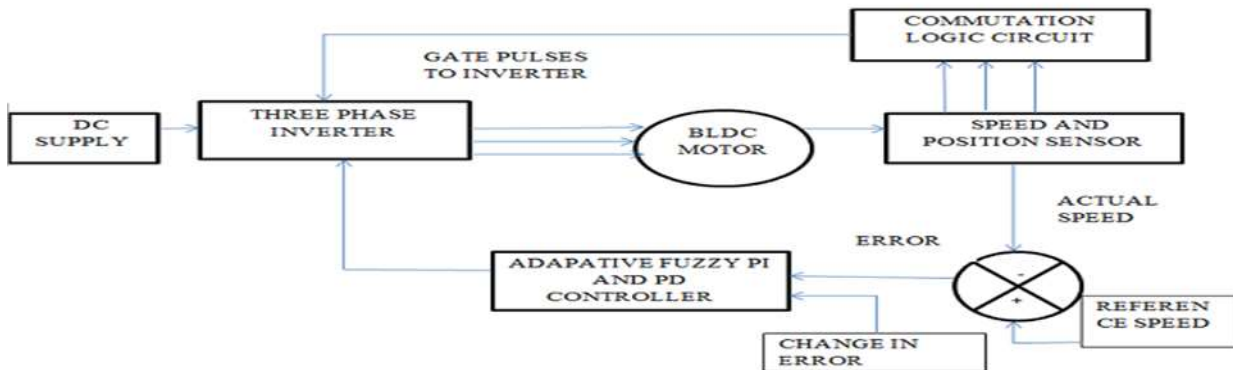


Fig.2. Block Diagram of the System

The block diagram of proposed system is shown in fig.2, consists of BLDC motor, three phase voltage source inverter, speed controller, commutation logic and position sensor. BLDC motor is fed by a three phase MOSFET based inverter. The PWM gating signals for firing the power semiconductor devices in the inverter is generated by the commutation logic block. The hall sensors are used as the position sensors. They detect the rotor position. Whenever rotor magnetic poles (N or S) pass near the hall sensor, they generate a high (1) or low (0) level signal, which can be used to detect the position of shaft. The commutation logic block generates emf based on the hall signals. The following truth table (Table-I) show the generation of emf based on hall signal.

Table-I Generation of Back EMF

HA	HB	HC	EA	EB	EC
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0

0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1
1	1	1	0	0	0

HA,HB,HC are the haff effect signal outputs. According to this EMF is generated,which produces corresponding gate signals to the three phase inverter,which get triggered according to the value of back EMF.

Table –II generation of gate signal

EA	EB	EC	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	1	0	0	0	1	1	0
-1	1	0	0	1	1	0	0	0
-1	0	1	0	1	0	0	1	0
1	0	-1	1	0	0	0	0	1
1	-1	0	1	0	0	1	0	0
0	1	-1	0	0	1	0	0	1

ADAPATIVE FUZZY PID CONTROLLER

The actual speed is sensed and the speed controller block process the error signal (difference between the reference and actual speed). Adaptive fuzzy PID controller is used as the speed controller in the proposed system. For comparison purpose, a PI controller is also incorporated. The proposed controller is a parallel combination of two controllers-fuzzy PI controller and fuzzy PD controller. Speed error ($e(k)$) and change in speed error ($ce(k)$) are given as inputs to the two controllers. Switching takes place between these controllers based on the error signal. The fuzzy PI controller improves the steady state response of the system and minimizes the steady state error.the fuzzy PD controller improves the transient response of the system and minimizes the rise time.

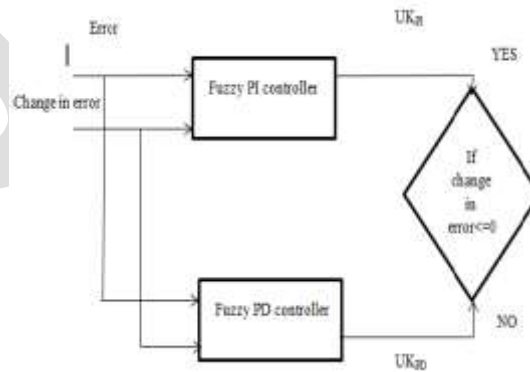


Fig.3.Architecture of Adapative Fuzzy PID Controller

Fig. 4 shows the basic structure of a fuzzy logic controller. Fuzzy logic linguistic terms are most often expressed in the form of logical implications, such as If-Then rules. These rules define a range of values known as fuzzy membership functions. Fuzzy membership

functions may be in the form of a triangle, a trapezoid, a bell as shows in fig. 6, or of another appropriate form. There are seven clusters in the membership functions, with seven linguistic variables defined as: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). Here two rule table is used, one for PI controller and another for PD controller, which are shown in Table-III and Table- IV. And final resultant is taken by switching action between these two which is shown in fig.8. Speed error (e) and change in speed error (ce) are used as the inputs to the speed controller. The output of the fuzzy-based proportional integral controllers is the gain FKPI and output of the fuzzy based proportional derivative controller is the gain FKPD. The fuzzy variable error has seven sets: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), and negative small (NS), negative medium (NM) and negative big (NB), with each set having its own membership function. The fuzzy variable change in speed error has also seven sets: PB, PM, PS, ZE, NS, NM and NB, with each set having its own membership function.

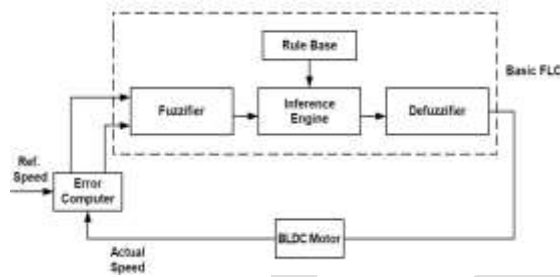


Fig.4. Structure of Fuzzy Logic Controller

Triangular membership functions are normally used. As the next step, the fuzzy IF-THEN inference rules are chosen. The number of fuzzy rules that are required is equal to the product of the number of fuzzy sets that make up each of the two fuzzy input variables. The conjunction of the rule antecedents is evaluated by the fuzzy operation intersection, which is implemented by the min operator. The fuzzy rules are evaluated using the fuzzy inference engine and an output for each rule is computed. The multiple outputs are transformed to a crisp output by the defuzzification interface. The process of decoding the output to produce an actual value for the controller gain is referred to as defuzzification. Thus, a fuzzy logic controller based centre-average defuzzifier is implemented.

Table -III Rules for Fuzzy PI Controller

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	NM	ZE	ZE
NM	PB	PB	PB	PM	PS	ZE	ZE
NS	PB	PM	PS	PS	PS	ZE	ZE
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	ZE	ZE	NM	NS	NS	NM	NB
PM	ZE	ZE	NS	NM	NB	NB	NB
PB	ZE	ZE	NM	NB	NB	NB	NB

Table - IV Rules for Fuzzy PD Controller

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZE

NM	PB	PB	PB	PM	PS	ZE	NS
NS	PB	PB	PM	PS	ZE	NS	NM
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PM	PS	ZE	NS	NM	NB	NB
PM	PS	ZE	NS	NM	NB	NB	NB
PB	ZE	NS	NM	NB	NB	NB	NB

SIMULINK MODEL

The simulation of the BLDC motor speed control with adaptive fuzzy PID controller is performed using MATLAB/SIMULINK. Parallel structure of fuzzy PI and fuzzy PD controllers is used as speed control circuit. The switching action takes place according to the error signal. The output of the controller is fed to a controlled voltage source which feeds the inverter. During regenerative mode we can connect a battery across circuit, it will get charged during that time. The decoder block generates the gate signals based on the hall signals. Fuzzy logic toolbox in MATLAB is used for the simulation. The controller is designed through FIS editor and is exported to the MATLAB workspace. Mamdani type of inference engine is used in the FIS editor. The waveforms of speed, torque, hall signals, back emf, stator currents, and gate pulses to the inverter are obtained for a reference speed of 3000rpm and -3000rpm. By setting positive and negative speed we get two modes of operation of BLDC motor. Fig .5 shows the simulink model of adaptive fuzzy pid controller based BLDC motor.

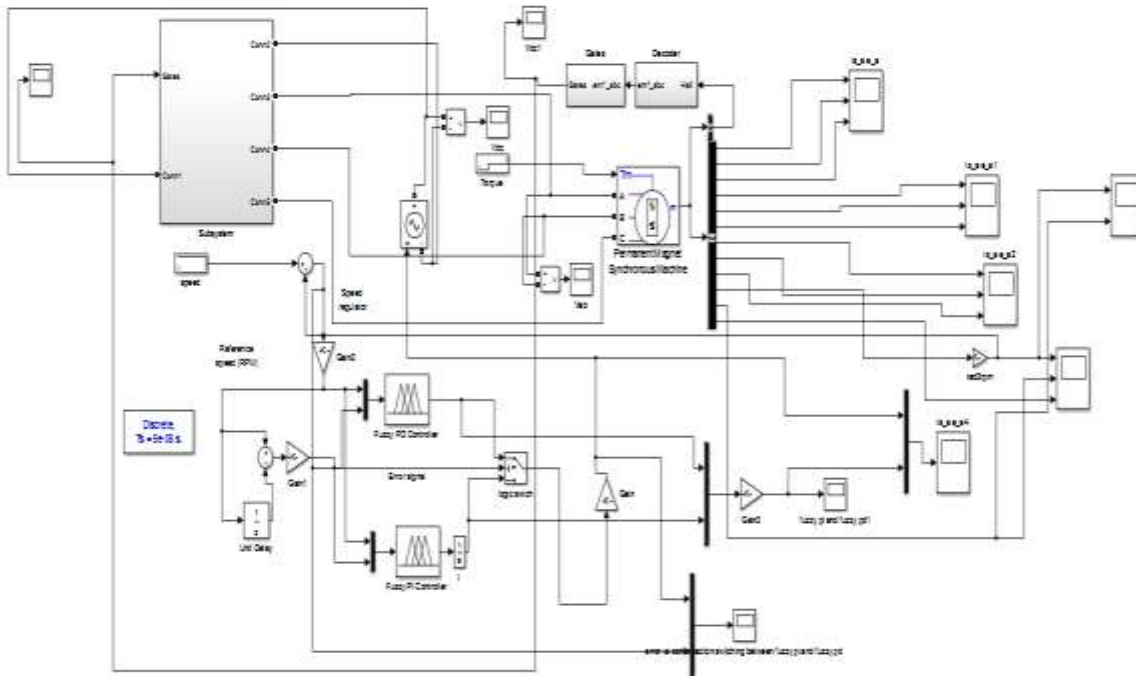


Fig.5.Simulink Model of Adaptive Fuzzy PID based BLDC Motor

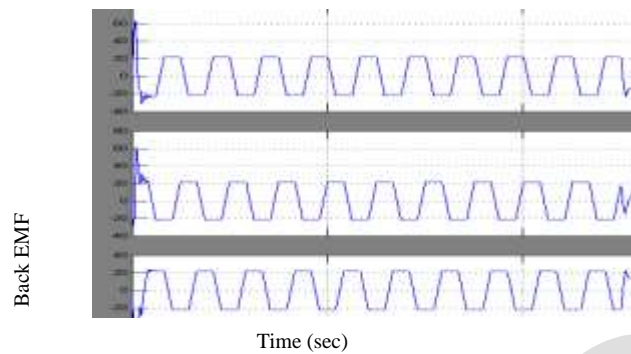


Fig.6. Back EMF Waveform

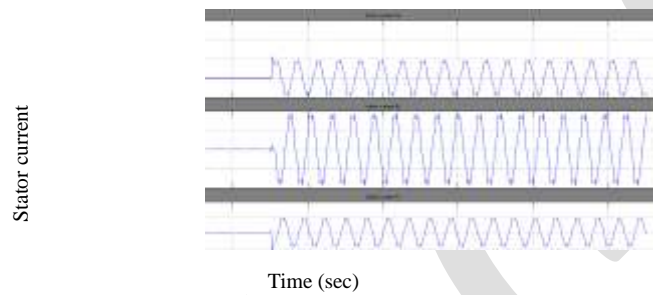


Fig .7.Stator Current Waveform

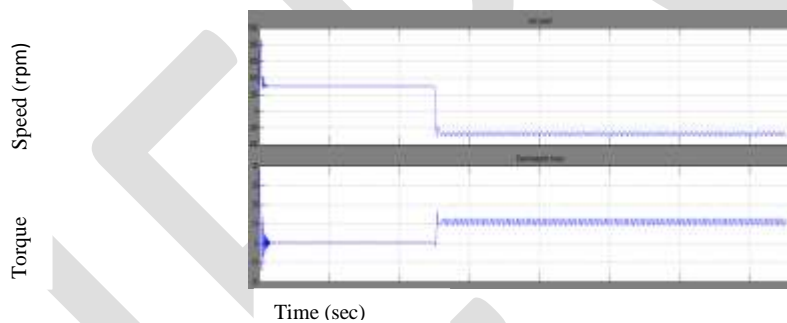


Fig.8. Speed and Torque Responses

CONCLUSION

Permanent-magnet brushless dc motors are more accepted and used in high-performance applications because of their higher efficiency, higher torque in low-speed range, high power density, low maintenance and less noise than other motors. In this paper, an adaptive fuzzy PID technique for BLDC motor has been introduced and verified using MATLAB simulations. The adaptive fuzzy PID controller is a parallel combination of fuzzy PD and fuzzy PI controllers and has the combined advantages of both. It was found that its settling time, overshoot, steady state error, recovery time, and undershoot were less than any other PI and PD controller. It also saves energy during regenerative braking without any loss of power.

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