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COMPARISON ANALYSIS OF DIFFERENT CONTROLLERS FOR PWM INVERTER FED PERMANENT MAGNET BRUSHLESS DC MOTOR

P.Elangovan, Dr.C.Kumar

Abstract –– This paper presents the performance evaluation of the fuzzy and Proportional and Integral control system applied to Permanent-Magnet Brushless DC Motor (PMBLDCM) with different Pulse Width Modulation(PWM) techniques. At first the comparison analysis is made between Sinusoidal PWM and Space Vector PWM inverter fed Permanent-Magnet Brushless DC Motor with the implementation of Proportional and Integral controller. From the analysis of Total harmonic distortion (THD) in the inverter current, Space Vector Pulse Width Modulation (SVPWM) technique was found to be better than Sinusoidal Pulse Width Modulation(SPWM) technique. However, the PI controller has some disadvantages such as: high starting overshoot, sensitivity to controller gains and sluggish response due to sudden load disturbance. Hence the Fuzzy logic controller is implemented in the feedback for SVPWM inverter fed PMBLDCM. Simulation result are presented and analyzed for both fuzzy and PI controllers. It is observed that fuzzy logic based controller gives better responses than traditional Proportional and Integral controller for the speed control of dc motor drives.

IndexTerms ––– Pulse Width Modulation ; Permanent Magnet Brushless DC Motor ; PI controller; Fuzzy logic Controller; Sinusoidal Pulse Width Modulation ; Space Vector Pulse Width Modulation ; Total Harmonic Distortion.

1 INTRODUCTION

Conventional dc motors are highly efficient and their characteristics make them suitable as servomotor. However, it needs a commutator and brushes which are subject to wear and required maintenance. The functions of commutator and brushes were implemented by solid-state switches that can realize maintenance-free motors. These motors are now known as brushless dc motors. Brushless dc motors are widely used in various applications. Two examples of them are electric vehicle and industrial machinery. Fuzzy logic controller which is presented by Zadeh in 1965, is a new controller [1]. Besides that, fuzzy logic controller is more efficient from the other controller such as proportional-integral (PI) controller. The comparison between them is needed to compare in what way the controller is efficient [2]. The reason why conventional controller is having low efficiency such as PI controller because the overshoot is too high from the set point and it may takes delay time to get constant and sluggish response due to sudden change in load torque and the sensitivity to controller gains K_i and K_p [3].

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PWM techniques:

Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Recent developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Hence, different circuit configurations namely multilevel inverters have become popular and considerable interest by researcher are given on them. Variable voltage and frequency supply to d.c drives is invariably obtained from a three-phase voltage source inverter. A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply. The most widely used PWM schemes for three-phase voltage source inverters are carrier-based sinusoidal PWM and space vector PWM. There is an increasing trend of using space vector PWM because of their easier digital realization and better dc bus utilization.

2 PULSE WIDTH MODULATION IN INVERTERS

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off

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periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as Pulse-Width Modulation Control.

PWM inverters are quite popular in industrial applications. PWM techniques are characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and to reduce its harmonic content. The different PWM techniques are as under:

(a) Single-pulse modulation

(b) Multiple pulse modulation

(c) Sinusoidal pulse width modulation

The carrier based PWM technique has been discussed in [1] and the corresponding equations related to it has been derived.

2.1 Sinusoidal PWM technique

The generation of gating signals with sinusoidal PWM are shown in fig.1. There are three sinusoidal reference signal corresponding to a phase to generate the gating signals for that phase [8]. Comparing the carrier signal with the reference phases V_{oa}, V_{ob} and V_{oc} produces the gating signals. The instantaneous line-to-line output voltage is $V_{ab} = V_s(g_1 - g_2)$. The output voltage as shown in fig.1 is generated by eliminating the condition that two switching devices in the same arm cannot conduct at the same time.

The normalized carrier frequency m_f should be odd multiple of three. Thus, all phase-voltage are identical, but 120° out of phase without even harmonics; moreover, harmonics at frequencies multiple of three are identical in amplitude and phase in all phases. For instance, if the ninth harmonic voltage in phase a is

$v_{aN9}(t) = \tilde{v}_9 \sin(9\omega t)$............ (1)

the corresponding ninth harmonic in phase b will be,

$v_{b9}(t) = \tilde{v}_9 \sin(9(\omega t-120°))$

$= \tilde{v}_9 \sin(9(\omega t-1080°)) = \tilde{v}_9 \sin(9\omega t)$.... (2)

Thus, the ac output line voltage v_{ab} does not contain the ninth harmonic. Therefore, for odd multiples of three times the normalized carrier frequency m_f, the harmonics in the ac output voltage appear at normalized frequencies f_h centered around m_f and its multiples, specifically, at

$N = jm_f \pm k$ .... (3)

For nearly sinusoidal ac load current, the harmonics in the dc link current are at frequencies given by

$n = jm_f \pm k \pm 1$ .... (4)

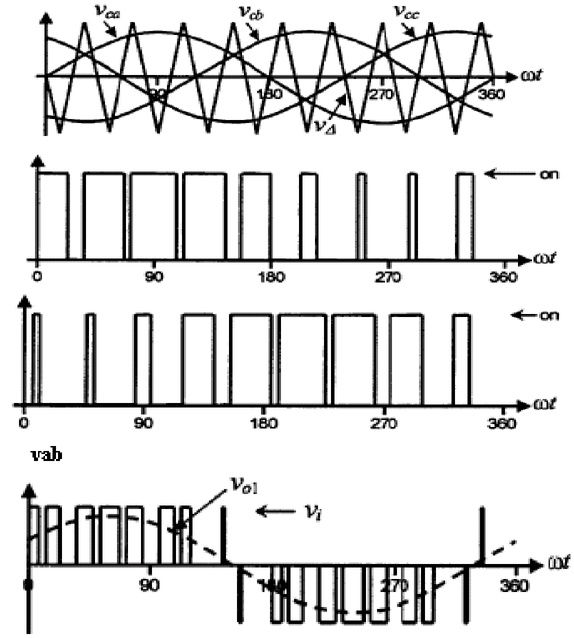

Fig.1 SPWM for three phase inverter

2.2 Space Vector PWM technique

The desired three phase voltages at the output of the inverter could be represented by an equivalent vector **V** rotating in the counter clock wise direction as shown in Fig.2. The magnitude of this vector is related to the magnitude of the output voltage and the time of this vector takes to complete one revolution is the same as the fundamental time period of the output voltage.

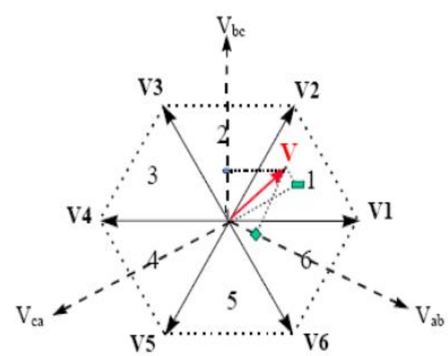

Fig.2 Output voltage vector in the plane.

Let us consider the situation when the desired line-to-line output voltage vector **V** is in sector 1 as shown in Fig.3.

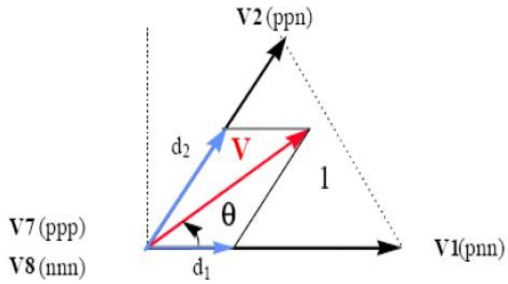

Fig.3 Synthesis of the required output voltage vector in sector 1.

This vector could be synthesized by the pulse-width modulation (PWM) of the two adjacent SSV's **V1** (pnn) and **V2** (ppn), the duty cycle of each being d_1 and d_2, respectively, and the zero vector(**V7**(nnn) / **V8**(ppp)) of duty cycle d_0:

$d_1V_1 + d_2V_2 = V = mV_ge^{je}$............... (5)

$d_1 + d_2 + d_0 = 1$ .... (6)

Where, $0 \le m \le 0.866$, is the modulation index. This would correspond to a maximum line-to-line voltage of $1.0V_g$, which is 15% more than conventional sinusoidal PWM as shown.

All SVM schemes and most of the other PWM algorithms use Eqns. (5) and (6) for the output voltage synthesis. The modulation algorithms that use non-adjacent SSV's have been shown to produce higher THD and/or switching losses and are not analyzed here, although some of them, e.g. hysteresis, can be very simple to implement and can provide faster transient response. The duty cycles d_1, d_2, and d_0, are uniquely determined from Eqns. (5) and (6) , the only difference between PWM schemes that use adjacent vectors is the choice of the zero vector(s) and the sequence in which the vectors are applied within the switching cycle.

3 STRUCTURES

3.1 Proportional-Integral (PI) Controller Structure

Fig. 4 shows the Proportional-Integral (PI) controller block diagram. The speed error E_N between the reference speed N_R and the actual speed N of the motor is fed to the PI controller, and the K_1 and K_2 are the proportional end integral gains of the PI controller.

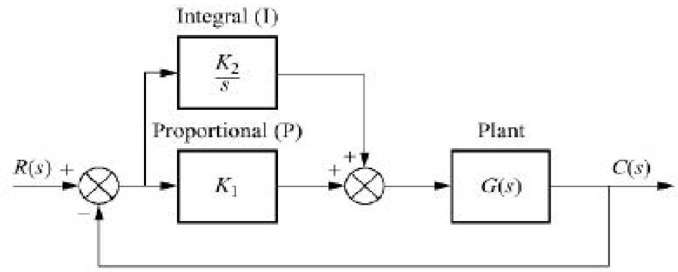

Fig.4 Block Diagram of PI controller

The P-I controller has the form

$E_1(S)/E_N(S) = (K_1S+K_2)/S$ ..... (7)

This is a phase-lag type of controller with the pole at the origin and makes the steady-state error in speed zero. The transfer function between the output speed N and the reference speed N_R is given by:

$N(S)/N_R(S) = (AK_1+AK_2S)/(K_1S^2+K_2S+K_3)$ .....(8)

Where, $A = C_1K_{CH}K$

$K_1 = R_ABT_M + C_1K_{CH}BT_M$

$K_2 = R_AB + K_2 + C_1K_{CH}B + AK_P$

$K_3 = AK_I$

$T_M = J/B$

K_I and K_P are controller gains, and R_A, B, T_M, etc., are motor and feedback constants shows in table 1. The above equation introduces a zero and therefore a higher overshoot is expected for a step change in speed reference.

3.2 Fuzzy logic controller structure

Fig. 5 shows the basic structure of fuzzy logic controller. Fuzzy logic's 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 [2]. Fuzzy membership functions may be in the form of triangle, a trapezoid, a bell or another appropriate form.

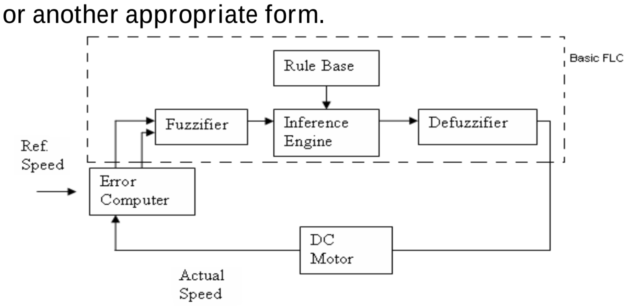

Fig. 5 Fuzzy logic controller

The inputs of the fuzzy controller are expressed in several linguistic levels show in fig.6, these levels can be described as positive big (PB), positive medium (PM), positive small

(PS), or in other levels. Each level is described by a fuzzy set.

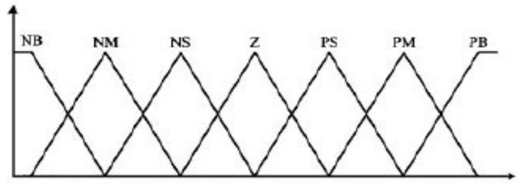

Fig.6 Seven levels of fuzzy membership function

In general, experience and expertise are required for the implementation of fuzzification in complex systems [3].

Fuzzy logic control doesn't need any difficult mathematical calculation, it only use simple mathematical calculation, but it can provide very good performance in a control system [4]. Thus, it can be one of the best available answers today for a board class of challenging controls problem. A fuzzy logic control consists of

(i) Fuzzification: This process converts or transforms the measured inputs called crisp values, into the fuzzy linguistic values used by the fuzzy reasoning mechanism.

(ii) Knowledge Base: A collection of the expert control rules (knowledge) needed to achieve the control goal.

(iii) Fuzzy Reasoning Mechanism: This process will perform fuzzy logic operations and result the control action according to the fuzzy inputs.

(iv) Defuzzification unit: This process converts the result of fuzzy reasoning mechanism into the required crisp value.

4 SIMULATION

To validate the control strategies as described, digital simulation were carried out on a converter dc motor drive system by using MATLAB/SIMULINK, the used parameters in these system are given in table 1.

Armature resistance (Ra)	0.5 Ω
Armature inductance (La)	8 mH
Back e.m.f constant (K)	0.55 V/rad/s
Mechanical inertia (J)	0.0465 kg.m2
Friction coefficient (B)	0.004 N.m/rad/s
Rated armature current (Ia)	10 A

Table 1. The parameter of dc motor drive system

4.1 Simulation results for SPWM and SVPWM techniques:

The THD when SPWM technique used is 20% whereas the THD when SVPWM technique used is only 2%.On observing fig.7 and fig.8, it is clear that the harmonic contents in the inverter current is more eliminated using SVPWM technique than SPWM technique.

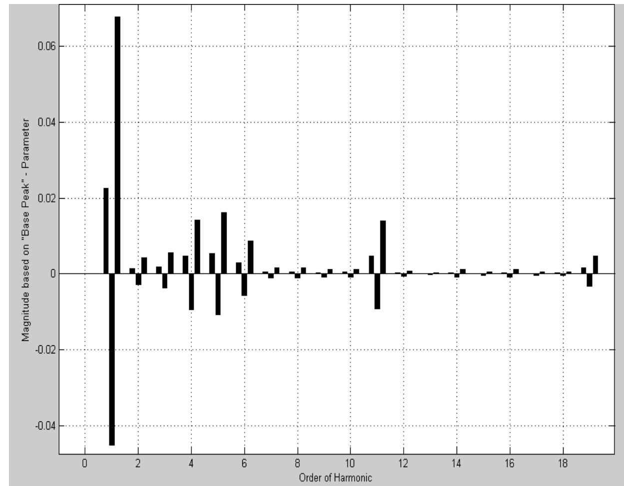

Fig.7 THD in current when SPWM technique used

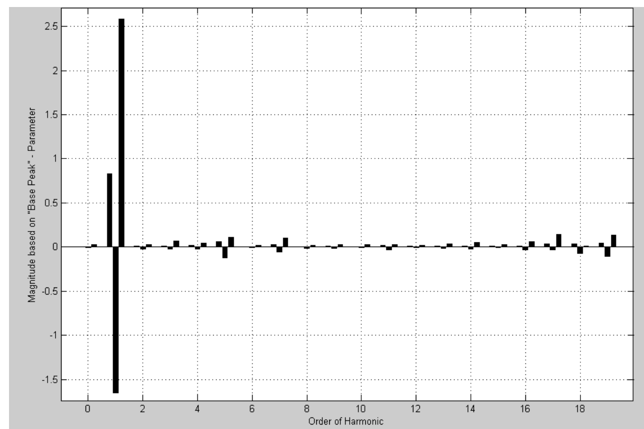

Fig.8 THD in current when SVPWM technique used

4.2 Simulation results for PI and Fuzzy logic controller:

The response of the drive system is obtained by setting the reference speed to 1500 r.p.m. The system speed response of fuzzy logic controller is shown in fig. 9. Fig. 11 shows the system speed response with fuzzy controller due to the load change and the load reference is 1400r.p.m. Compare to PI controller, it seen no starting overshoot and sudden load change problem for fuzzy logic controller. The system speed response of PI controller is shown in fig. 10. Fig. 12 shows the system speed response with PI controller due to the load change from 1500 r.p.m to 1400 r.p.m. Clearly observe that, the speed response of PI controller shows in fig. 10 has high starting overshoot from the set point. It approximate to 1900 r.p.m.

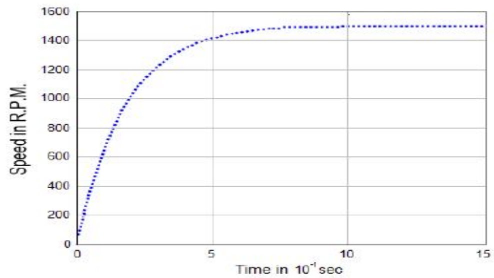

Fig.9 Speed response of fuzzy logic controller (N_{ref} = 1500 r.p.m)

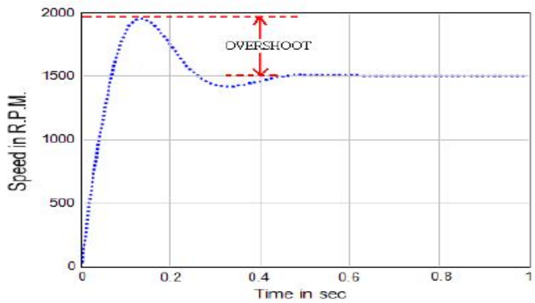

Fig.10 Speed response of PI controller (N_{ref} = 1500 r.p.m)

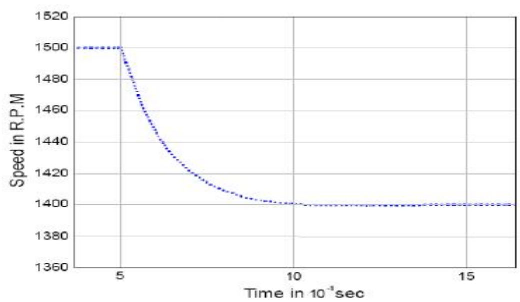

Fig.11 Speed response of fuzzy logic controller (N_{ref} = 1400r.p.m)

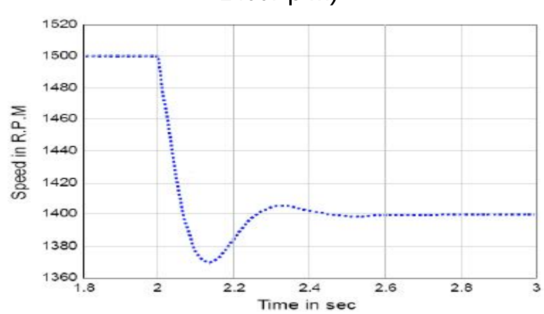

Fig.12 Speed response of PI controller (Nref = 1400 r.p.m)

5 CONCLUSION

This paper is intended to evaluate the performance of different controllers (PI and Fuzzy logic controller) when they are used in the feedback path of PWM inverter fed PMBLDC drive. In this paper, the performance evaluation of SPWM and SVPWM techniques also determined based on the Total harmonic distortion in the inverter output current. From the simulation results, it is concluded that SVPWM technique is more preferable than SPWM technique to control the output voltage and current of the inverter.

It is observed that fuzzy logic controller provide important advantages over the traditional PI controller like limiting the overshoot in speed, thus the starting current overshoot can be reduced. This paper also demonstrates the successful application of fuzzy logic control to a phase controlled converter dc motor drive. Fuzzy logic was used in the design of speed controllers of the drive system and the performance was compared with that of PI controller.

The advantages of the Fuzzy controller are that it determines the number of rules automatically, reduces computational time, learns faster and produces lower errors than other method. By proper design a fuzzy logic controllers is much better than PI controllers for the speed control of dc motor drives.

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