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Self Tuning Adaptive Control and Performance Comparison of Brushless DC Motor for Constant Speed Analysis

K. Thufail Muhammed[a] and K. Balaji[b]

[a]Research scholar, Department of EEE, St.Peter's University, Chennai, Tamil Nadu, India. Email: thufailmuhammedped@gmail.com
[b]Associate Professor, Department of EEE, St.Peter's University, Chennai, Tamil Nadu, India

Abstract: A vector control of electrical motor drive is an effective process on Brushless DC Drive system over scalar control scheme. Speed parameters control scheme is notable factors on vector scheme for of BLDC drive. Estimation scheme is varied due to varying load parameters conditions and its obtained better estimation of parameters was limited for particular varying parameters conditions. Here, extracting and finding parameters was implemented using self tuning adaptive scheme using vector control approach. Adaptive self tuning control scheme is more reliable for varying load parameters conditions. The speed of Brushless DC Motor is obtained for varying load and motor parameters varying conditions. A constant proportional integral derivative scheme are comparing with fuzzy self tuning proportional integral derivative for speed performance of Brushless DC Motor. Proposed vector loops is a form of self tuning adaptive speed control, phase current extraction and space vector Pulse width modulation. Simulation implementation and verification was tested about performance using MATLAB/Simulink Results.

Keywords: BLDC Motor (Brushless DC Motor), Rotation Per Minutes (RPM), Fuzzy Logic Control, PID Control (Proportional Integral Derivative), Proportional gain (k_p), Integral gain (k_i), Derivative gain (k_d) Space Vector Modulation (SVM).

1. INTRODUCTION

An application brushless DC Motor on automotive drive is increases gradually due to its unique performance over induction motor drive, Such as low power maintenance, high speed performance. An automotive drives covers industrial application, home application, High Voltage DC (HVDC), lower electromagnetic Torque and smart city application. Speed control system plays a crucial role on motor drive due to varying parameters and load capacity [1]. Vector of brushless DC Motor is classified into two types such as sensor and sensor less Vector. Sensor based vector scheme is more reliable on low to high speed application (50 RPM to 1500RPM) over sensor-less base vector . Sensor-less vector is having low reference magnitude of electromotive force and current across phase performance on Brushless DC Motor drive while runs in low speed operation whereas sensor of brushless DC motor performance better in wide speed variation (50 RPM to 1500 RPM) but sensor scheme is required external components and additional circuits for implementing vector for brushless DC Motor.

In order to reduce computational burden of structure and reducing external elements are reduces in self tuning sensor based vector control [2-6].

An adaptive self tuning control law is applied for tuning and control of speed performance of brushless DC Motor drive over standard control procedures. Proportional integral control and proportional integral derivative control law is achieving performance for high speed region where as in high speed region, those control laws are resulting lower performance across Brushless DC Drive. So an intelligent self- tuning law is necessary to improving performance of speed and also estimation of gain across proportional integral control and proportional integral derivative control [7-9]. In this paper fuzzy based adaptive control law is introduces to improving performance of speed for load varying and parameters varying conditions. Proposed performance was compared with self tuning proportional integral and derivative control for varying load and parameters region. This control structures is not requiring any current sensing elements, position sensing elements for controlling brushless DC Motor drive parameters. A two space vector based pulse width modulation is implemented to control of motor drive system using direct (d) and quadrature axis (q) reference frame conversion via adaptive self tuning using neuro-fuzzy logic control and also simulation results are compared with constant proportional integral control and proportional integral control to verify about performance of proposed BLDC motor

2. BRUSHLESS DC MOTOR

Brushless DC Motor is contains Stator and rotor as outer layer and inner layer structure respectively. Rotor includes magnets and stator includes windings and names propose brushes are unavailable. The semiconductor switches is uses to drive commutation signals to turn stator winding current by rotor position feedback signals such as hall signals or estimated signals. In this regard, brushless DC Motor is equivalent to a reversed DC commutator motor which stationary form of conductor while magnets are rotates. So brushless DC Motor is frequently integrated a sensor on stator or rotor to finding positions. The proposed dynamic model of brushless DC Motor is explained by following equations as stator winding equations which is given in Figure 1.

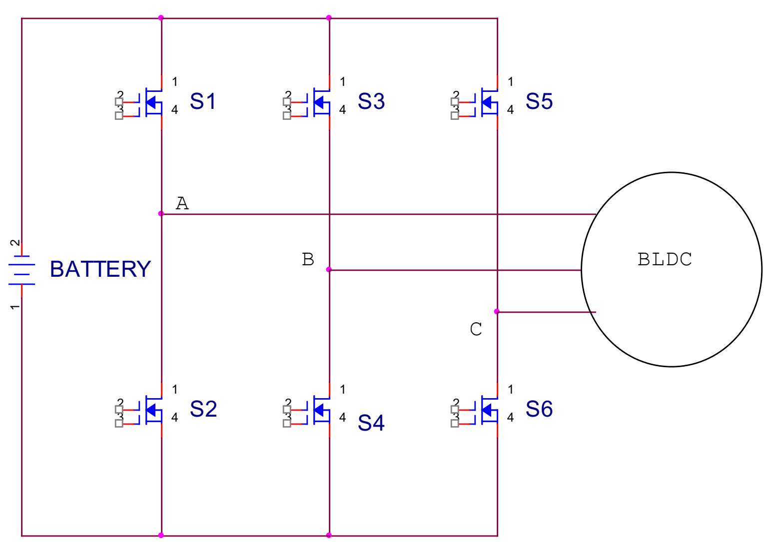


Figure 1: Three Phase Inverter fed Brushless DC Motor

$$U_{an} = R_a i_a + \frac{d}{dt}(L_{aa} i_a + L_{ba} i_b + L_{ca} i_c) + e_a \tag{1}$$

$$U_{bn} = R_b i_b + \frac{d}{dt}(L_{ab} i_a + L_{bb} i_b + L_{cb} i_c) + e_b \tag{2}$$

$$U_{cn} = R_c i_c + \frac{d}{dt}(L_{ac} i_a + L_{bc} i_b + L_{cc} i_c) + e_c \tag{3}$$

Here we assume as $R_a = R_b = R,$ (4)

$$L_{aa} = L_{bb} = L_{cc} = L_s, \tag{5}$$

$$L_{ba} = L_{ab} = L_{ca} = L_{ac} = L_{bc} = L_{cb} = M \tag{6}$$

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \begin{bmatrix} L_s & M & M \\ M & L_s & M \\ M & M & L_s \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{7}$$

Since $i_a + i_b + i_c = 0$ and with $L_s - M = L$, we obtained as

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{8}$$

where,

R = stator resistance per phase for phase a to c

L = Stator inductance per phase and presume to be phase a to b

i_a, i_b & i_c stator current

Immediate induced electro motive force (EMF) of proposed BLDC is written as:

$$e_a = f_a(\theta_r)\, \lambda_p \omega_m \tag{9}$$

$$e_b = f_b(\theta_r)\, \lambda_p \omega_m \tag{10}$$

$$e_c = f_c(\theta_r)\, \lambda_p \omega_m \tag{11}$$

where,

ω_m, The rotor mechanical speed

θ_r, Rotor electrical position

3. CONTROL LAW USING SELF TUNING METHOD

The proposed control schemes is self tuning of PID using fuzzy logic control for performed to improving speed performance of Brushless DC Motor drives and analysis are carried out for variable load changing conditions and variable parameters changing conditions are analysis using simulation results. Methodology of constant proportional Integral and derivative control as well as adaptive self tuning of proportional integral and derivative control using fuzzy logic with are described in bellow chapters III[i] and III[ii] respectively.

(a) Self Tuning Control using PID

The speed control of adaptive self tuning proportional integral and derivative control for adjusting proportional gain, integral gain and derivative gain constant internally for varying load and parameters. Operation of adaptive self tuning scheme is similar that of basic PID control scheme and additionally self tuning of proportional (k_p), integral (k_i) and derivative constant (k_d) due to parameters variation. The mathematical expression of proposed implementation of adaptive PID is given as:

$$y(t) = K_p \left[e(t) + T_d \frac{d(e)}{d(t)} + \frac{1}{T} \int_0^T e(t)\, d(t) \right] \quad (12)$$

$$y(t) = \left[K_p e(t) + K_d T_d \frac{d(e)}{d(t)} + K_i \int_0^T e(t)\, d(t) \right] \quad (13)$$

where, $k_i = \frac{k_p}{T_i}$, $k_d = k_p \cdot T_d$

(b) Self Tuning Control using Adaptive Fuzzy-PID

The control of adaptive fuzzy self tuning of PID controller is includes as proportional (k_p), integral (k_i) and derivative constant (k_d) and it is tuned by fuzzy control logic controller. The coefficient of classical PID controller is not able to tune accurately by varying load parameters and unmeasured motor parameters conditions is shown on Table 2. So self tuning of proportional integral and derivative control system is necessary to regulate speed at time and reducing peak overshoot constant to improving performance of brushless DC Motor. The basic fuzzy structure and self tuning of PID using fuzzy is shown in Figure 2 (a) and (b)

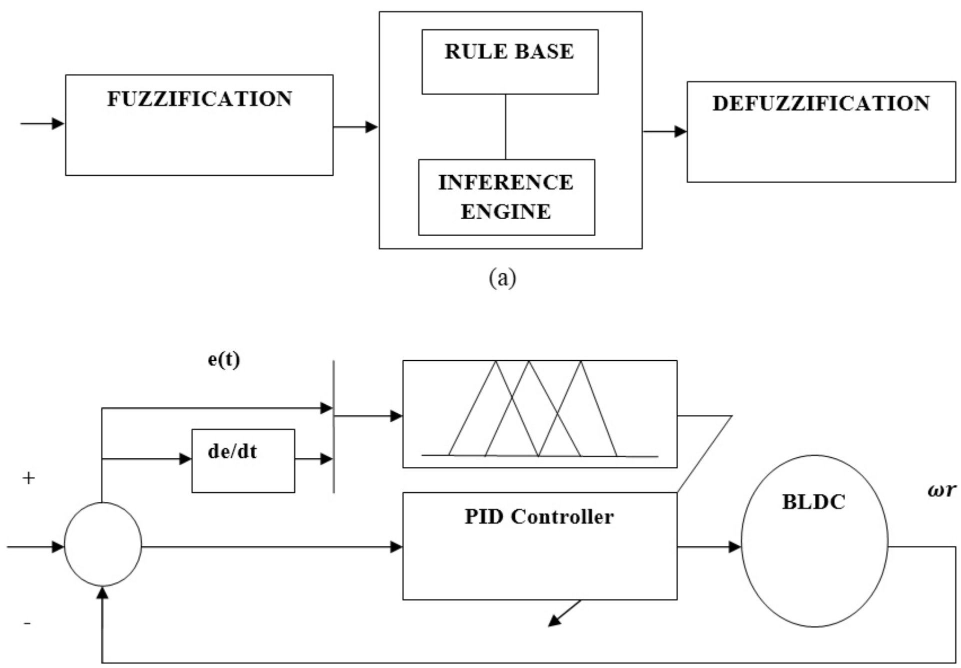


Figure 2: Tuning control structure (a) structure of Fuzzy Logic Control (b) self tuning of PID using Fuzzy logic control

In Figure 2 (b), $e(t)$ is a calculated error by comparing of actual speed and reference speed signals. de(t) is a derivative form of obtained error $e(t)$. PID tuning by fuzzy logic control is delivered a non-linear mapping from error ($e(t)$) and derivation of error ($de(t)$). The fuzzy rules are designed is based on motor parameters and load variation and belongs to PID controller. Rules and fuzzy inputs are accumulation or fuzzification to form output of fuzzy logic control. Accumulation and defuzzification is designed by proposed centroid method. In proposed fuzzy design structure is shown in Figure 3, here $e(t)$ and $de(t)$ are the input error and derivative error and obtained tuning value are k_p, k_d and α which is used to calculate k_i using equation is given in (14) and it is applied to proposed PID controller to estimate constant gain for speed control aspects.

$$k_i = \frac{k_p^2}{k_d + \alpha} \tag{14}$$

Proposed k_p, k_d is calculated as bellow for range between 0 to 1

$$k_p = \frac{k_p - k_{p\,\min}}{k_{p\,\max} - k_{p\,\min}} \tag{15}$$

$$k_d = \frac{k_d - k_{d\,\min}}{k_{d\,\max} - k_{d\,\min}} \tag{16}$$

Proposed adaptive self tuning of PID using fuzzy logic is implemented by Fuzzy rules and it is created due to varying parameters of brushless DC Motor and load variation conditions as given in Table IV. controlled speed based quadrature axis is calculated and direct axis estimation is applied to proposed Space vector pulse width modulation for controlling inverter fed BLDC Motor control is shown in Figure 3.

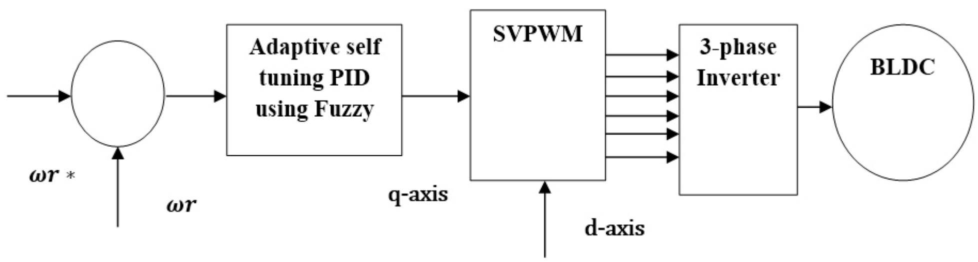


Figure 3: Proposed SVPWM based vector control scheme using adaptive fuzzy self tuning of PID

Table 1
Proposed fuzzy rules for self tuning PID control

De/e	*NB*	*NM*	*NS*	*PB*	*PM*	*PS*	*ZO*
NB	K_p – B K_d – B α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2
NM	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2	K_p – B K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2
NS	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2
PB	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2
PM	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2	K_p – B K_d – S α – 2
PS	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3	K_p – B K_d – S α – 2
ZO	K_p – S K_d – B α – 5	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – S K_d – B α – 5	K_p – S K_d – B α – 4	K_p – S K_d – B α – 3	K_p – B K_d – B α – 3

Proposed space vector pulse width modulation is implemented using estimation of reference voltage is derived from α and β reference frame below equation [17] for mentioned on Figure 3 using switching state of proposed inverter configuration which is shown on Table 2 and 3.

Table 2
Switching State of VSI

State	*Leg A*			*Leg B*			*Leg C*		
	S_1	S_4	V_{an}	S_3	S_6	V_{bn}	S_5	S_2	V_{cn}
1	on	off	V_d	on	off	V_d	on	off	V_d
0	off	on	0	off	on	0	off	on	0

Table 3
Switching State of SVPWM

Switching state (Three phases)	*ON-state switch*	*Definition*
[1 1 1]	S_1, S_3, S_5	
[0 0 0]	S_4, S_6, S_2	0
[1 0 0]	S_1, S_6, S_2	$\vec{V}_1 = \frac{2}{3} V_d e^{j0}$
[1 1 0]	S_1, S_3, S_2	$\vec{V}_1 = \frac{2}{3} V_d e^{j\frac{\pi}{3}}$
[0 1 0]	S_4, S_3, S_2	$\vec{V}_1 = \frac{2}{3} V_d e^{j\frac{2\pi}{3}}$
[0 1 1]	S_4, S_3, S_5	$\vec{V}_1 = \frac{2}{3} V_d e^{j\frac{3\pi}{3}}$
[0 0 1]	S_4, S_6, S_5	$\vec{V}_1 = \frac{2}{3} V_d e^{j\frac{4\pi}{3}}$
[1 0 1]	S_1, S_6, S_5	$\vec{V}_1 = \frac{2}{3} V_d e^{j\frac{5\pi}{3}}$

$$\vec{V}_{\text{ref}} = V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + aV_b + a^2 V_c\right) \tag{17}$$

Similarly,

$$\left|\vec{V}_{\text{ref}}\right| = \sqrt{V_\alpha^2 + V_\beta^2},\ \alpha = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right)$$

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + e^{j\frac{2\pi}{3}} V_b + e^{-j\frac{2\pi}{3}} V_c\right) \tag{18}$$

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + \cos\frac{2\pi}{3} V_b + V_a + \cos\frac{2\pi}{3} V_c\right) + j\,\frac{2}{3}\left(\sin\frac{2\pi}{3} V_b - \sin\frac{2}{3} V_c\right) \tag{19}$$

By equating the real and imaginary parts derived by,

$$V_\alpha = \frac{2}{3}\left(V_a + \cos\frac{2\pi}{3}V_b + \cos\frac{2\pi}{3}V_c\right)$$

$$V_\beta = \frac{2}{3}\left(0V_a + \sin\frac{2\pi}{3}V_b - \sin\frac{2\pi}{3}V_c\right)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \cos\frac{2\pi}{3} & \cos\frac{2\pi}{3} \\ 0 & \sin\frac{2\pi}{3} & \sin\frac{2\pi}{3} \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{20}$$

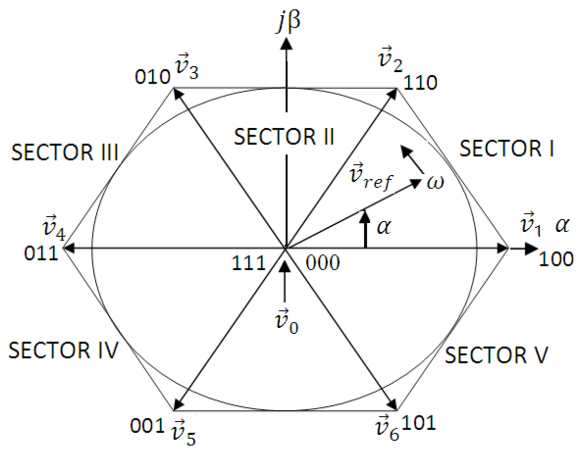


Figure 4: Space vector diagram for two-level inverter

Table 4
Motor parameters

Parameters	*Value*
Nominal Power (HP)	$P_n = 10$
Nominal speed (RPM)	$w_n = 1800$
Nominal torque (N.m)	$T_n = 39.5$
Inductance in *d*-axis (H)	$Ld = 22.1.\ 10^{-3}$
Inductance in *q*-axis (H)	$Lq = 91{:}1.\ 10^{-3}$
Armature winding resistance (Ω)	$R = 6.51.\ 10^{-1}$
Flux linkage (Wb)	$\lambda = 67.09.\ 10^{-1}$
Coulomb friction coefficient (N-m)	$F_c = 10^{-1}$
Viscous friction coefficient (N.m.s/rad)	$F_v = 1.10^{-1}$
Static friction coefficient (N.m)	$F_s = 6.4.10^{-1}$
Static friction decreasing rate (rad/s)	$\eta_s = 2$
Rotor and load inertia (kg.m2)	$j = 1.10^{-1}$
Number of pole pairs	$p = 2$

4. SIMULATION RESULTS AND DISCUSSION

The proposed control and inverter fed brushless Dc Motor control was implemented using separate PID tuning and adaptive self tuning of PID using fuzzy logic control. The based on automotive application speed control is achieved by proposed self tuning control law to improving performance of motor over variable load and parameters conditions. The obtained simulation results was showing steady state performance and reduced peak overshoot is drawn at 015 sec using Adaptive self tuning PID using fuzzy logic control. Whereas PID control is reaches speed at 0.2sec for same parameters, changing parameters conditions and wide load performance. The compared performance is clearly shows as per Figure 5 to 6. Figure 5 is clearly showing about stator current smoothness is obtained on proposed control scheme over classical PID. As well as aim of topology on speed performance are drawn quickly over classical PID controller for load parameters changing conditions. an adaptive fuzzy based PID self tuning scheme is adequate solution for improving speed performance brushless DC Motor by generating exact quadrature axis reference for proposed space vector pulse width modulation.

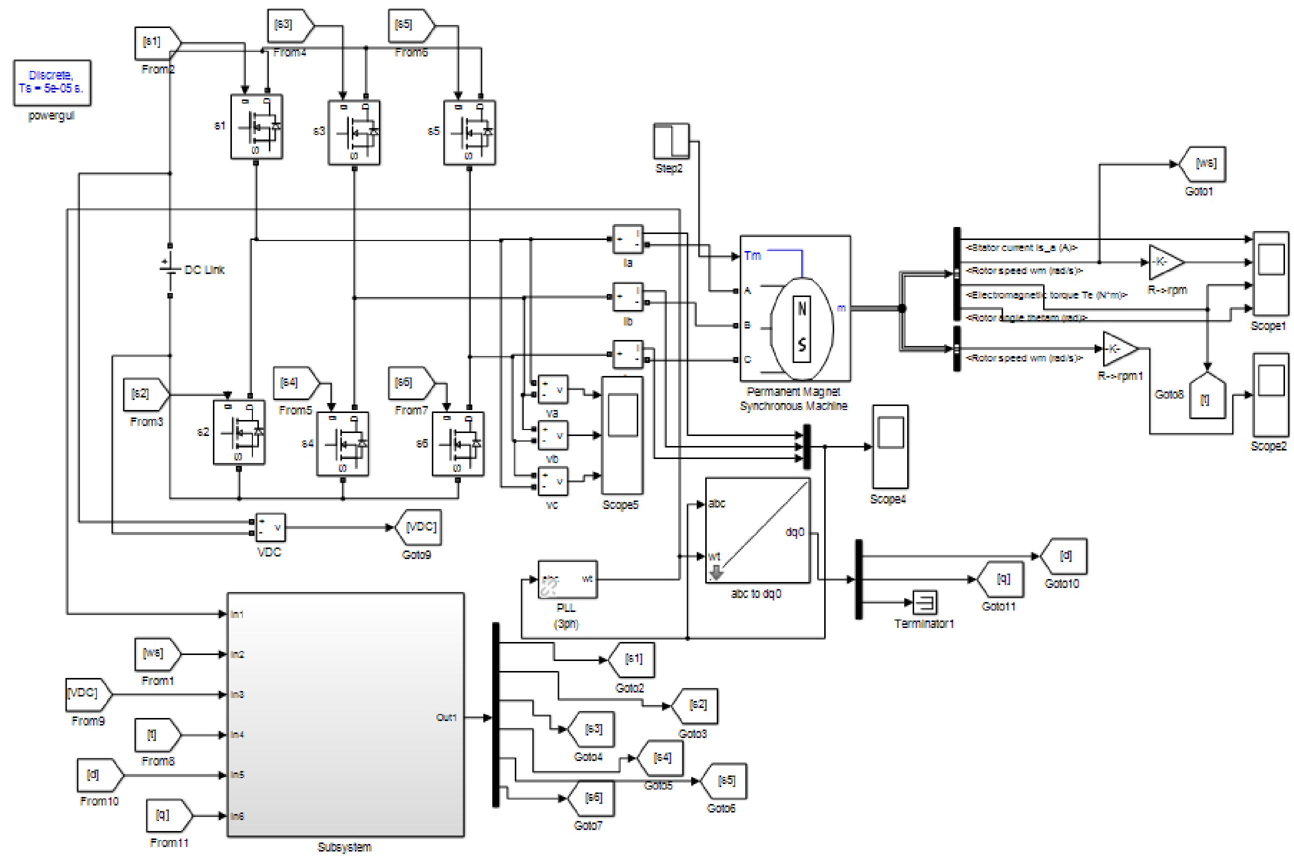


Figure 5: Simulation implementation of proposed circuit and control configuration

5. CONCLUSION

Increasing need of brushless DC Motor drive in automotive application, an adequate control system is needed to implement for achieving speed steady state performance over classical methodology. If motor load and internal parameters variation is changed, general control scheme is not able to control for wide load and parameters variation motor drives. Proposed adaptive self tuning of PID is calculated for obtain steady state speed performance with respect parameters variation. Classical simulation results are showing about weakness on steady state performance on time and changing load and parameters conditions. Space vector based pulse width modulation is used to provide accurate excitation through inverter system and its additional factors to improve brushless DC Motor performance. The performance was proved using MATLAB/Simulink software results.

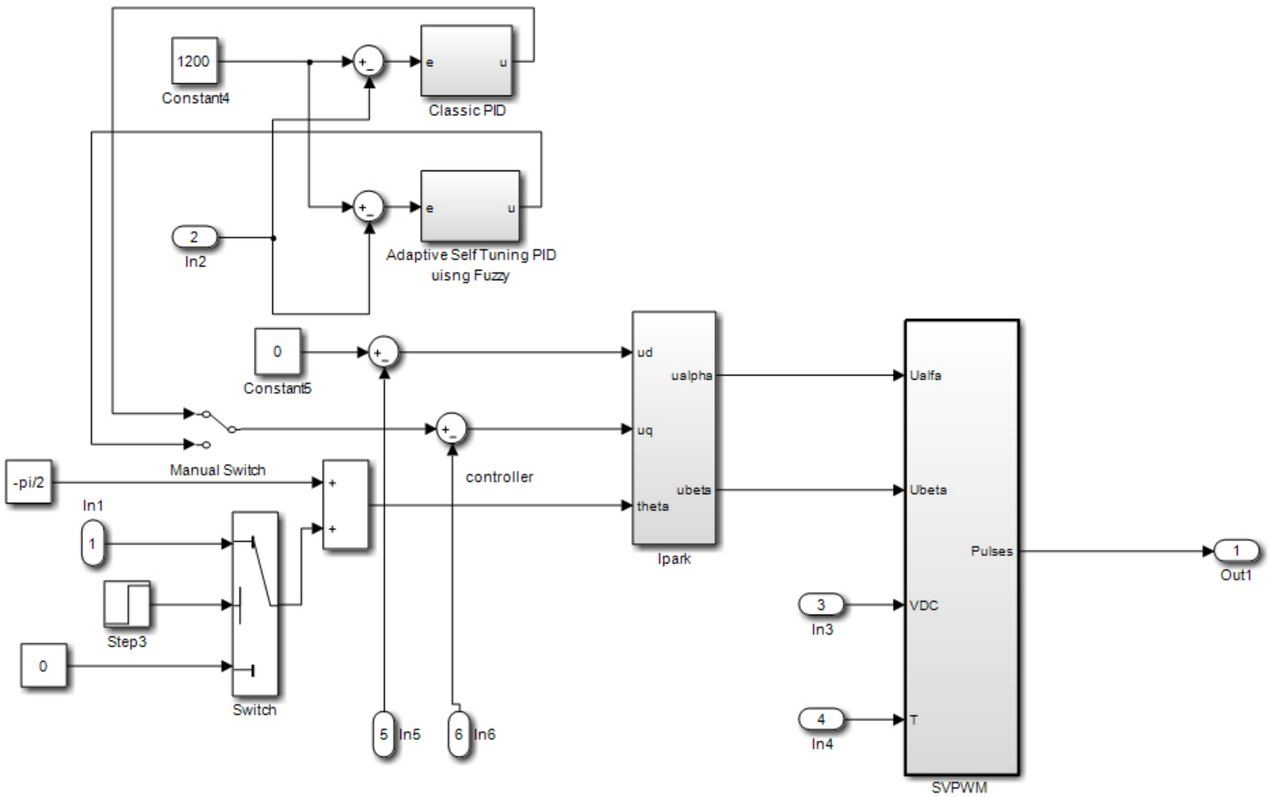
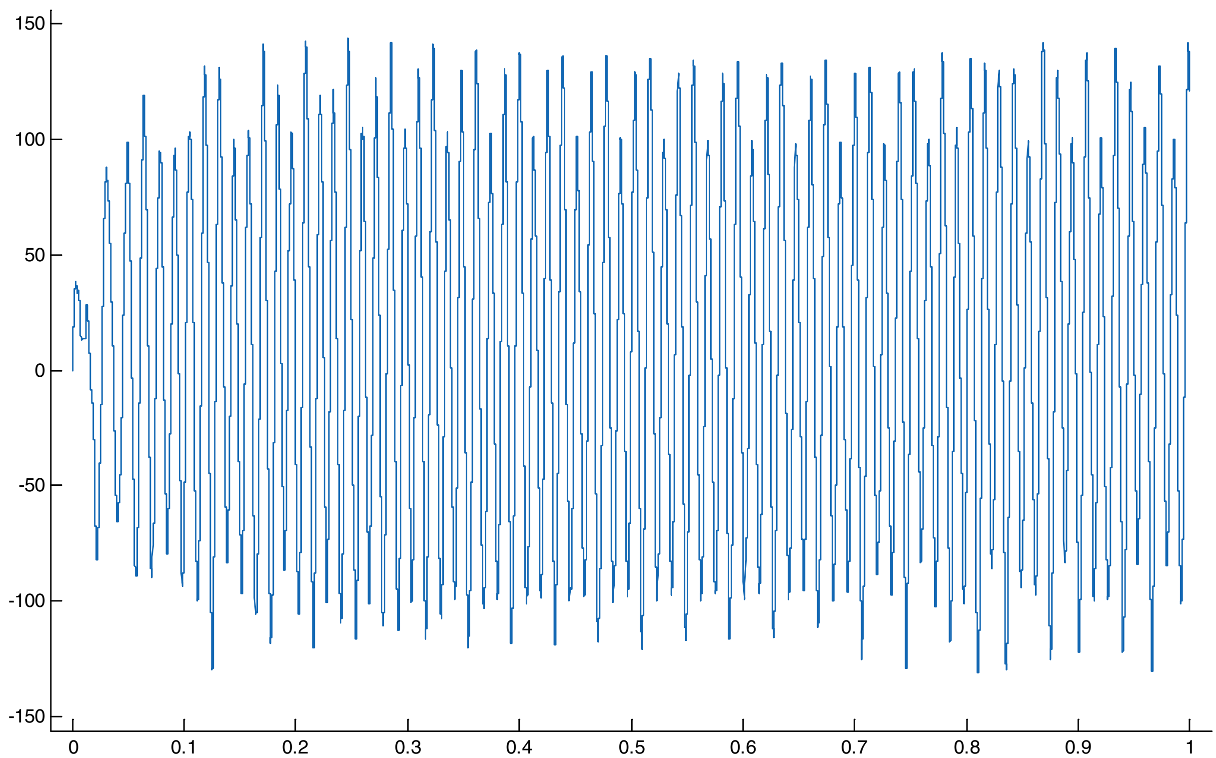
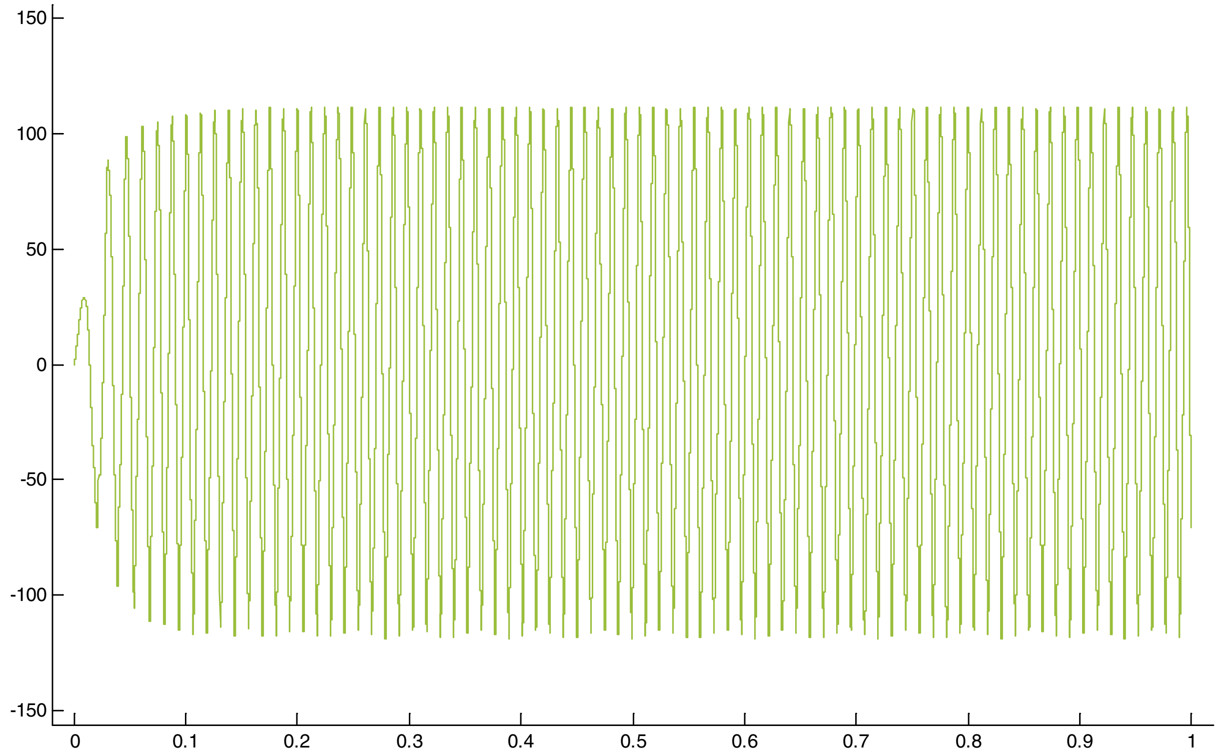


Figure 6: Proposed control circuit using PID and adaptive self tuning PID using Fuzzy logic control

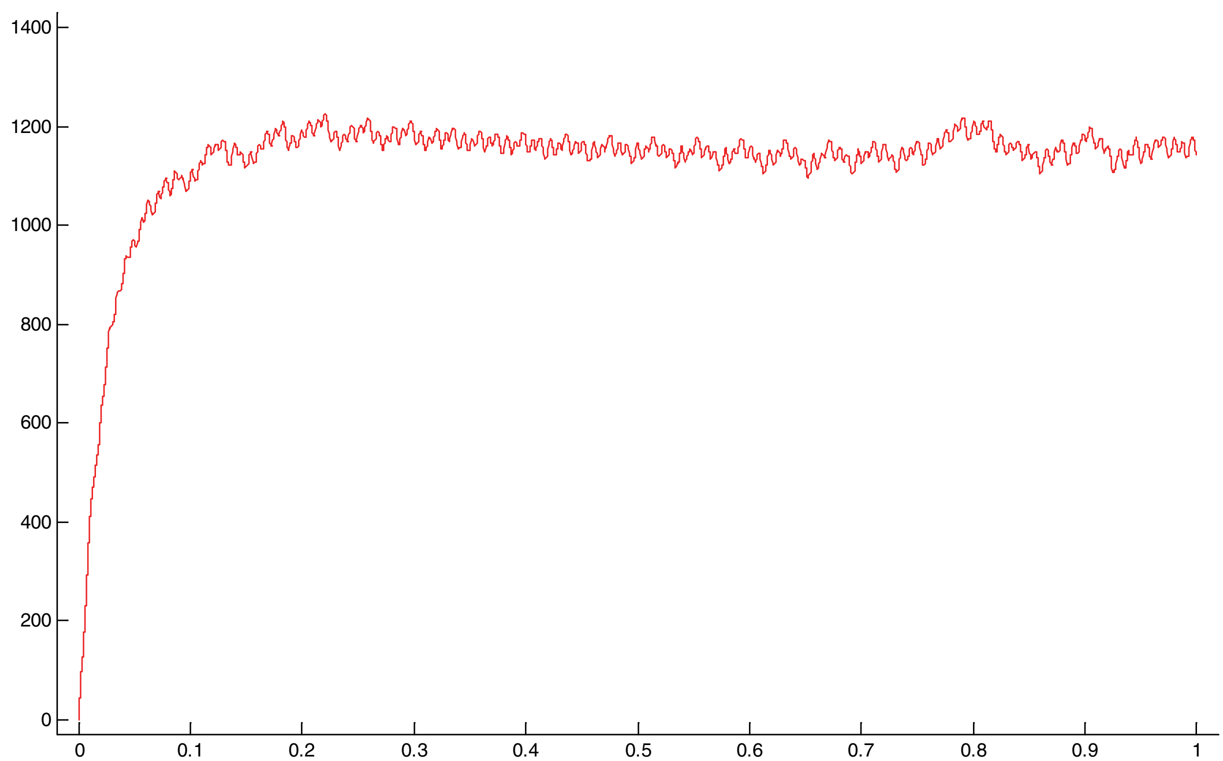


(a)

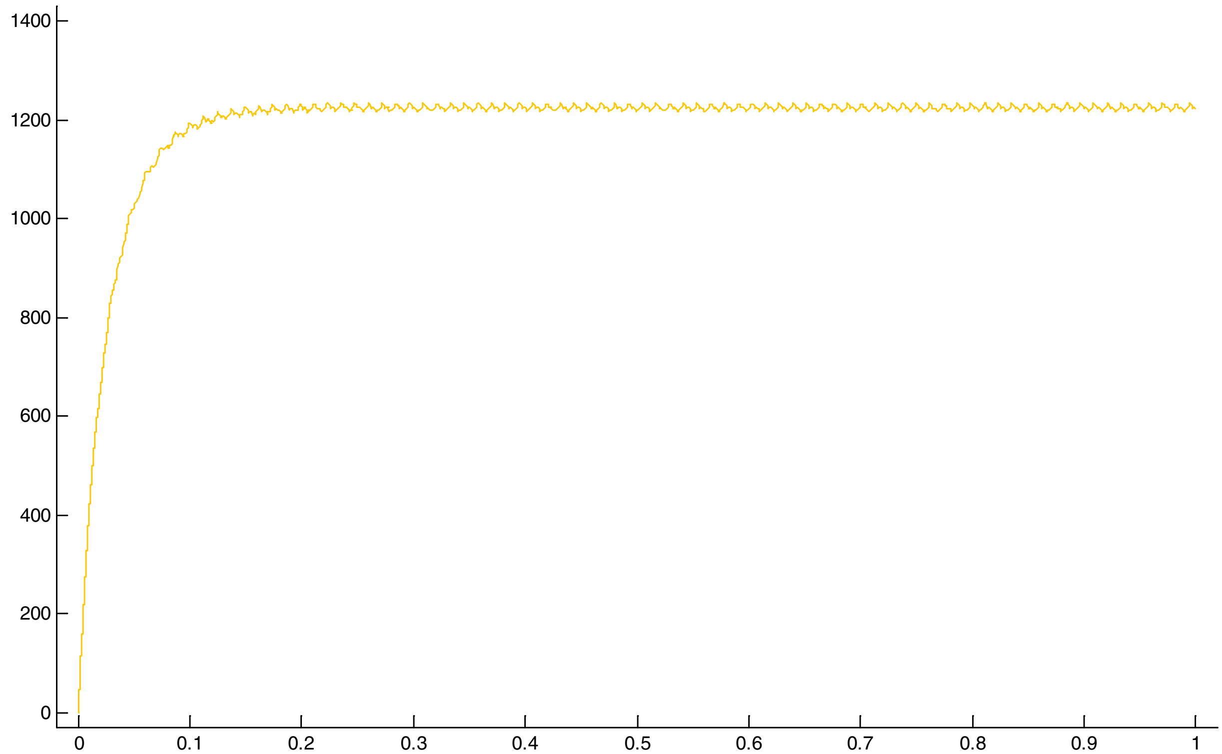


(b)

Figure 7: Stator current performance comparisons (a) using classical PID controller (b) using proposed adaptive self tuning PID using Fuzzy Logic control



(a)



(b)

Figure 8: Rotor speed performance comparisons (a) using classical PID controller (b) using proposed adaptive self tuning PID using Fuzzy Logic control

REFERENCES

[1] C. Rusu, I. Birou, M.M. Radulescu, A. Bara, “Developing Embedded System Platform for Testing PMSM Drives”, IEEE 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), Pages: 677-682, Published: 2014

[2] Meng, G., Xiong, H. and Li, H., (2009), November. Commutation torque ripple reduction in BLDC motor using PWM_ON_PWM mode. In Electrical Machines and Systems, 2009. ICEMS 2009. International Conference on (pp. 1-6). IEEE.

[3] T. H. Kim and M. Ehsani, “Sensorless control of BLDC motors from near-zero to high speeds,” IEEE Trans. Power Electron., Vol. 19, No. 6, pp. 1635–1645, Nov. 2004.

[4] Li, H., Zheng, S. and Ren, H., (2017). Self-Correction of Commutation Point for High-Speed Sensorless BLDC Motor with Low Inductance and Nonideal Back EMF. IEEE Transactions on Power Electronics, 32(1), pp.642-651.

[5] Kim, S.K., Lee, J.S. and Lee, K.B., (2016). Offset-Free Robust Adaptive Back-Stepping Speed Control for Uncertain Permanent Magnet Synchronous Motor. IEEE Transactions on Power Electronics, 31(10), pp.7065-7076.

[6] Qiang, F., Hui, L. and Hai-tao, Z., (2006), December. Single-current-sensor sliding mode driving strategy for four-switch three-phase brushless DC motor. In Industrial Technology, 2006. ICIT 2006. IEEE International Conference on (pp. 2396-2401). IEEE.

[7] Chaoui, H., Khayamy, M. and Aljarboua, A.A., (2017). Adaptive Interval Type-2 Fuzzy Logic Control for PMSM Drives with a Modified Reference Frame. IEEE Transactions on Industrial Electronics.

[8] H. Chaoui, P. Sicard, and W. Gueaieb, “ANN-Based Adaptive Control of Robotic Manipulators with Friction and Joint Elasticity,” IEEE Trans.Ind. Electron. Vol. 56, No. 8, pp. 3174–3187, Aug. 2009.

[9] C. W. de Silva, Intelligent Control Fuzzy Logic Applications. CRCPress, 1995

[10] Kyoung K. A., Bao K. N., Yoon H. S. (2007). Self Tuning Fuzzy PID Control for Hydraulic Load Simulator. Int. Conference on Control, Automation, and Systems 2007, 345-349. Ceox, Seoul, Korea.

[11] Kyoung K. A., Bao K. N. (2006). Position Control of Shape Memory Alloy Actuators using Self Tuning Fuzzy PID Controller. Int. J. of Control, Automation, and Systems, Vol.4 (6): 756-762.

[12] Mohamed .M. Ismail" Improving the Performance of the DTC Saturated Model of the Induction Motor in case of Two Level and Three Level VSI using GA and PSO algorithms" Electronics, Communications and Computers (JEC-ECC), pp 79-84, Mar.2012.

[13] Harris, T.J., Macgregor, J.F. and Wright, J.D., (1980). Self-tuning and adaptive controllers: an application to catalytic reactor control. Techno metrics, 22(2), pp.153-164.