PERFORMANCE ESTIMATION OF STABILITY AND FAULT ANALYSIS FOR BLDC MOTOR USING PID TUNE ANN CONTROLLER WITH STATE SPACE MODEL

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Abstract: *In this article, the steady state stability and internal fault analysis of the Brushless DC motor (BLDC) with Hybrid PID-ANN Controller has been analyzed with state space model. The steady state stability analysis of the proposed controller has been examined using state plan and Lyapunov Technique. The proposed controller performance is analyzed for sudden change in load, speed variation, Open circuit fault (OCF) and Short Circuit Fault (SCF) occur disturbance condition of the motor has been presented and also the controller performance is compared with conventional controller. A prototype model 300W, 50Hz system is developed and built, the transient and dynamic performances for the BLDC motor are compared and presented. From the simulation and experimental results, it is found that the PID-ANN Controller can have better controller compared with conventional controller.*

Keywords : *BLDC Motor, PID Tuned Artificial Neural Network, Stability analysis, DSP Processor.*

1 Introduction.

In recent, Brushless Direct Current Motor (BLDC) is generally used in a various applications because of its simplicity and robust control, excellent speed characteristics, high speed, high torque achieve from same power density and motor manufacturing cost is very less compared to existing high frequency drives. In the recent years many researchers developed an adaptive and nonlinear control techniques have been widely used to control the BLDC drives [1]-[5]. The speed control and rotor position of the BLDC motors are very important in servo application, hybrid vehicles, fuel pumps, various industrial applications, etc. Taehyung Kim et al [6] have analyzed the stator turn fault of the BLDC motor using Winding Function Theory. The static and dynamic performance motor under the fault condition was not presented. Sewoong Kim [7] have demonstrated and presented the internal fault and dynamic analysis of the BLDC motor. The delta winding connections have been used for the fault analysis. The fault diagnosis methods are the FTC (Fault Tolerant Control) technique algorithm and FDI (Fault Detection Isolation) techniques have been used.

Satish Rajagopalan et al [8] have designed and demonstrated the rotor bar fault detection using WVD (Wigner Ville Distributions) and WFR (Windowed Fourier Ridges) methods were presented. The concentration of this paper used to identify the rotor faults in electric motor working under persistently changing working conditions. Min Dai et al [9] have developed the fault analysis of a PMBLDC motor using FE method (Finite Element Method) was analyzed and presented. The transient and dynamic performance of the motor has been analyzed and performance of the motor was tested in running and various load condition. The short circuit condition fault analysis also presented with various condition. Sakshi Solanki [10] have designed and developed the speed control of BLDC drive with ANN (Artificial Neural Network) Controller was presented. The PID controller performance and ANN controller was tested and compared the performance and presented. The dynamic and transient performances of the BLDC motor were not presented.

Laxmiprasanna ch et al [11] have described the speed control of BLDC motor using ANN controller was presented. The performance of the controller has been presented with speed variation. The steady state and dynamic performance of the controller was not considered. The controller is planned to tracks varieties of speed references and settles the yield speed amid stack varieties. R. A. Gupta et al [12] have discussed the intelligent control technique for PMBLDC motor was presented. Different AI strategies for PMBLDC motor are reported and provided the system quick response for the specialists and rehearsing engineers those are working in the area of PMBLDC drives.

Ramya A et al [13] have demonstrated the speed control of BLDC with self tuned fuzzy PID (FPID) controller was presented. The fuzzy PID controller and self tuned FPID controller was presented with speed control performance analysis and comparison of the controller were presented. The transient and dynamic performance of the motor was presented. Navaneethakkannan.C et al [14] have demonstrated and developed the ANFIS controller based BLDC motor was presented. The rotor position controller performance of the motor was described. The ANFIS controller found and solved the problem of uncertainties and nonlinearities by the reference input of the motor. The transient and dynamic performance of the motor was presented with steady-state condition [15]. Julio C. G. Pimentel et al [16] have discussed the steady state stability analysis of the BLDC motor was presented. The transfer function of the BLDC motor model has been designed and used to found the system stability condition. The mathematical model of the motor has been tested with various time delay sources. The time delay sources are SPT (Set Point Tracking) and LDR (Load Disturbance Rejection).

K. Neethu et al [17] have described the speed control of BLDC motor with sensor less technology was presented controlled by fuzzy logic. Recognition of Rotor Position must be finished utilizing sensor less strategy that was deciding the zero intersection purposes of BEMF (Back Electromotive Force). The performance of the controller and transient, dynamic analysis of the motor were not present. The stability analysis and controller performance analysis was not clearly presented [18]. V.Jaya lakshmi et al [19] have developed the ANFIS based SSC (Stator Short Circuit) fault for BLDC motor was presented. The dynamic performance of the motor was considered and steady state analysis of the motor performance was poor by used in the ANFIS controller. The design procedure of the controller and motor was not clearly present. Speed control and power factor improvement was described using ANFIS and fuzzy logic controller [20]. The motor performance was developed and speed was controller by fuzzy logic [21]. Lukman A. Yusuf et al [22] have designed and developed the GA-PID based position tracking control of BLDC motor was presented. The GD-PID controller performance was compared to fuzzy logic controller and found that GA based controller shown better results. The dynamic and steady state performance of the motor was not presented [23,24].

It is absorbed from the above literatures that the internal fault attain in the motor and motor performance variation against supply voltage fluctuation (fault condition) and sudden change in load have critical part in the plan of rapid drives. The PID-ANN Controller is required to have the speed direction, high effectiveness and better execution in the season of speed and load aggravation. Considering the above certainties in view, the PID-ANN Controller based BLDC motor has been planned and the execution is dissected for evaluating different response. The steady state stability analysis of the proposed system has been analyzed using the state space model. The mathematical model of the system has been simulated using MATLAB. A 300W,50Hz BLDC motor was built and performance of the controller is compared with exiting work.

2. The proposed PID-ANN Controller based BLDC motor and Mathematical Modeling

The block diagram of the proposed PID-ANN Controller based BLDC motor with inverter is shown in fig.1. The primary stage three stage AC voltage is change over in to DC voltage Vdc by utilizing rectifier circuit. The rectifier output DC voltage is convert into 3 phase AC voltage using the inverter circuit. The motor fault detection sensed by the sensor and the error signal is send to the error finder unit. The speed of the motor can be sensed by the pulse type tacho generator. The controller feedback is used as the motor sensing speed at the time of motor in the fault condition. The actual speed of the motor and reference speed of the motor are compared and found the error detector. The distinction error speed is computed and to create the new error signal. The generated new error signal is given to controller unit. The PID-ANN Controller produces the control pulses to the bridge circuit depended on the error signal.

The two feedback loops are used in the PID-ANN Controller. First one is external speed controlling loop and second one is internal current controlling loop. The motor current is attaining the maximum peak value, the internal current controller reduces the generation of the PWM pulses. In the first speed controlling loop, tacho generator is used to find the actual speed (Ns) and final Ns is send to the error finder unit, the reference speed Nr also is given to the error finder and compare the both speed and calculate the final error (e). The final error (e) and previous error (e_{prov}) are generating the change in error (ωe). The ωe and e are the input of the FTANN controller. The controller output is given PWM generation unit. The previous PWM generation Signal P(q-1) and newly developed PWM generation signal P(q) are compared and calculated from the proposed controller. The controller produced the new change in PWM generation signal (θ) and it is given to inverter circuit to control the output. To attain the final error (e) is zero by changing the PWM generation signal is send to the inverter circuit [11].The simulation is used to estimate the input gain and output gain signals of the proposed controller.

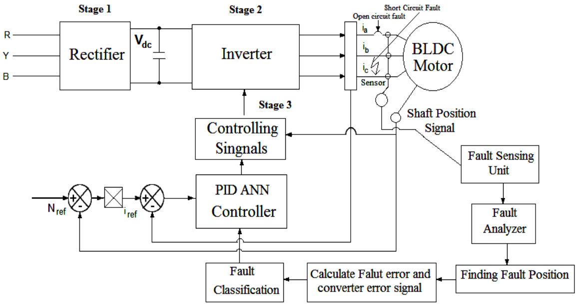


Fig.1: Block Diagram of the proposed controller

2.1 Mathematical Modeling of the BLDC motor with Controller

The closed loop block diagram of the BLDC motor with PID-ANN Controller is shown in fig.2. The transfer function of the motor can be obtained from the fig.2 by using Newton's Law. The assumption is made for there are no losses in the motor torque for accuracy and simplification.

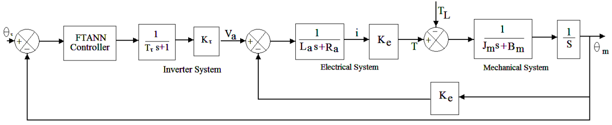


Fig. 2 Equivalent model of the BLDC motor with controller

The torque T is related to Ia (armature current) by a constant of K.

$$T = K_e I_a \qquad (1)$$

The angular velocity ω_m is related to the generation of motor EMF e_b. the e_b can be written as

$$e_b = K_e \omega_m = K_e \frac{d\theta_m}{dt} \qquad (2)$$

From the Fig 2 the equation is modeled based on the combination of Newton's Second Law
and Kirchhoff's law;
Applying Newton's Second Law

$$T = J_m \frac{d^2\theta_m}{d^2t} + B_m \frac{d\theta}{dt} \qquad (3)$$

Applying Khirchhoff's Law,

$$V_a - e_b = L_a \frac{dI_a}{dt} + I_a R_a \qquad (4)$$

Equating equation (1) =(3)

$$K_e I_a = J_m \frac{d^2\theta_m}{d^2t} + B_m \frac{d\theta_m}{dt} \qquad (5)$$

Substitute (2)in (5) and we get,

$$V_a - K_e \frac{d\theta_m}{dt} = L_a \frac{dI_a}{dt} + I_a R_a \qquad (6)$$

By applying the Laplace Transform in (5) and (6) the equation can be written as in terms of S and the constant K_e taken as K

$$K I_a(s) = J_m s^2 \theta_m(s) + B_m s\theta_m(s) \qquad (7)$$

$$V_a(s) - Ks\theta_m(s) = L_a s I_a(s) + I_a(s) R_a \qquad (8)$$

Equation (7) can be written as

$$I_a(s) = \frac{J_m s^2 \theta_m(s) + B_m s\theta_m(s)}{K} = \frac{s\theta_m(s)(J_m s + B_m)}{K} \qquad (9)$$

$I_a(s)$ equation (9) can be substitute in (8)

$$V_a(s) - Ks\theta_m(s) = L_a s\left[\frac{s\theta_m(s)(J_m s + B_m)}{K}\right] + \left[\frac{s\theta_m(s)(J_m s + B_m)}{K}\right] R_a \qquad (10)$$

$$V_a(s) = \frac{s\theta_m(J_m s + B_m)(L_a s + R_a) + K^2}{K} \qquad (11)$$

The transfer function equation of the motor output θ_m and input V_a can be obtained and written as

$$\frac{\theta_m(s)}{V_a(s)} = \frac{K}{(J_m s + B_m)(L_a s + R_a) + K^2} \qquad (12)$$

The transfer function of the inverter is

$$\frac{V_a(s)}{V(s)} = \frac{K_\tau}{1 + T_\tau s} \qquad (13)$$

Taking the inverse Laplace transform of the equation (12) and we get the state space equations. The BLDC motor is designed by multiple currents as the third current is dependent of the other two. From the equation (3,4 and 12) the nonlinear state space equations with state variables i_a,i_b, and θ_m. The state space equations are shown in equation (14). The BLDC motor specification is given in table 1. [22].

$$\dot{X} = AX + BU$$

$$\begin{bmatrix} \dot{i}_a \\ \dot{i}_b \\ \dot{\theta}_m \end{bmatrix} = \begin{bmatrix} -R_a \frac{1}{L_a} & 0 & 0 \\ 0 & -R_a \frac{1}{L_a} & 0 \\ 0 & 0 & -B_m \frac{1}{J_m} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ \theta_m \end{bmatrix} + \frac{1}{3L_a} \begin{bmatrix} 2 & 1 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & \frac{3L_a}{J_m} \end{bmatrix} \begin{bmatrix} V_a - e_b \\ V - K_\tau \\ \theta_m \end{bmatrix} \qquad (14)$$

Table I BLDC motor specification

Symbol	Parameter	Value
R_a	Phase Resistance	4.3 Ω
L_a	Phase Inductance	1μH
$K=K_e=K_b$	Torque Constant	1.4 N-m/A
J_m	Moment of Inertia	8×10^{-4} kg-m^2/rad
B_m	Damping Ratio	8×10^{-5} N-m/s
T	Torque	160 mNm
P	Pole Pairs	1
K_τ	Inverter Gain	596

3. Result and Discussion

3.1 Stability Analysis

3.1.1 Lyapunov Stability Analysis

Theorem 1: In Lyapunov Stability Analysis [25,31], the model is asymptotically stable if and only if for any Q = QT > 0 there exists a unique P = PT > 0 such that the below equation is satisfied

$$A^T P + PA = -Q, Q = Q^T > 0, Q = I_a \qquad (14)$$

Where Q is positive symmetry matrix or definite matrix

Theorem 2: The model is asymptotically stable if and only if the pair (A, D) is observable and the algebraic Lyapunov below equation has a unique positive definite solution.

$$A^T P + PA = Q, Q = D^T D > 0 \qquad (15)$$

Where A,D are the closed loop equation of the state space model. The transfer function of the BLDC motor equation (12) can be converting in to state space equation by using MATLAB coding.

$$A = \begin{bmatrix} -0.897 & 0.00225 & 0.152 & -2.18 \times 10^{-6} \\ -5.925 & 0.99 & 199.1 & -0.0060 \\ -0.10028 & -35.9 \times 10^{-5} & 0.727 & -0.4071 \times 10^{-6} \\ -1320 & 0 & 0 & 0 \end{bmatrix},$$

$$= \begin{bmatrix} 0.2568 \times 10^{-5} & 0.005296 & 41.35 \times 10^{-6} & 1 \end{bmatrix}^T,$$

$$C = \begin{bmatrix} 1326 & 0 & 0 & 0 \end{bmatrix}, D=0 \qquad (16)$$

The algebraic Lyapunov equations are solved by using the "dlyap" MATLAB software. By using this equation (16) the solutions are obtained:

theorem 1:

$$P = \begin{bmatrix} 26.79 \times 10^6 & 63.09 \times 10^6 & 0.3656 \times 10^7 & -0.128 \times 10^5 \\ 62.567 \times 10^6 & 0.0299 \times 10^6 & 19.42 \times 10^8 & -770.060 \\ 3.6978 \times 10^8 & 1.598 \times 10^7 & 9.789 \times 10^9 & -4.7175 \times 10^5 \\ -1.6920 \times 10^4 & -789.0236 & -5.963 \times 10^5 & 24.0693 \end{bmatrix}$$

theorem 2:

$$P = \begin{bmatrix} 26.76 \times 10^6 & 62.99 \times 10^6 & 0.3746 \times 10^7 & -0.139 \times 10^5 \\ 61.978 \times 10^6 & 0.0309 \times 10^6 & 19.51 \times 10^8 & -768.276 \\ 3.5976 \times 10^8 & 1.609 \times 10^7 & 9.691 \times 10^9 & -4.8275 \times 10^5 \\ -1.7001 \times 10^4 & -790.036 & -6.052 \times 10^5 & 23.6132 \end{bmatrix}$$

Examining the positive definiteness of the matrix P, the Eigen λ values are obtained as follows

$$\lambda_1 = \begin{bmatrix} 1 \\ 30.9684 \\ 13.579 \times 10^6 \\ 0.9675 \times 10^8 \end{bmatrix}, \quad \lambda_2 = \begin{bmatrix} 6.968 \times 10^{-6} \\ 28.6104 \\ 13.657 \times 10^6 \\ 0.9622 \times 10^8 \end{bmatrix}$$

Hence, theorem 1 and 2 solutions are positive definite and the Lyapunov test indicates that the proposed controller with BLDC under consideration is stable. In the above analysis it is conform that the proposed controller satisfies the equation (14) and (15) and there by conformed the stable condition. The stability and convergence of the overall proposed system can be proved by the Lyapunov stability analysis method.

3.1.2 State Plane Analysis

State plan analysis is the important method for analysis the nonlinear system behaviors. The two variables $V_a(s)$ and $\theta_m(s)$ are used in the state plan analysis plot. The state plan analysis is analyzed using PPLANE tool.

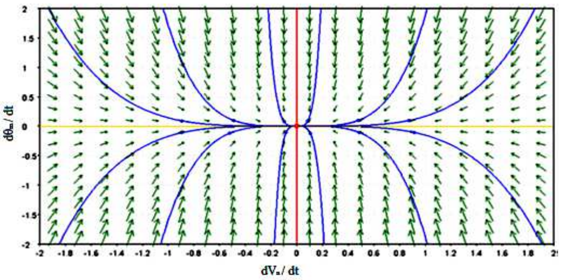


Fig 3 State Plan Analysis of the proposed system

The point (x,y) of the grid, the arrow representing the magnitude and direction of the vector. The plan result seems in three dimensions. One is point (0, 0) is a steady equilibrium position for the system, if the pointer in a solution plot is showing toward it, the system is assumed to be stable. By using the equation no (14) the state plan drawn by using the PPLANE shown and it is shown in fig 3. It is absorbed from the above fig 3, the plot converges to (0,0) for all the initial conditions and $\lambda_{1,}\lambda_2 \leq 0$ is satisfied. it is concluded from the state plan analysis the proposed controller based BLDC motor is that asymptotically stable.

3.2. Design of Hybrid PID-ANN Controller

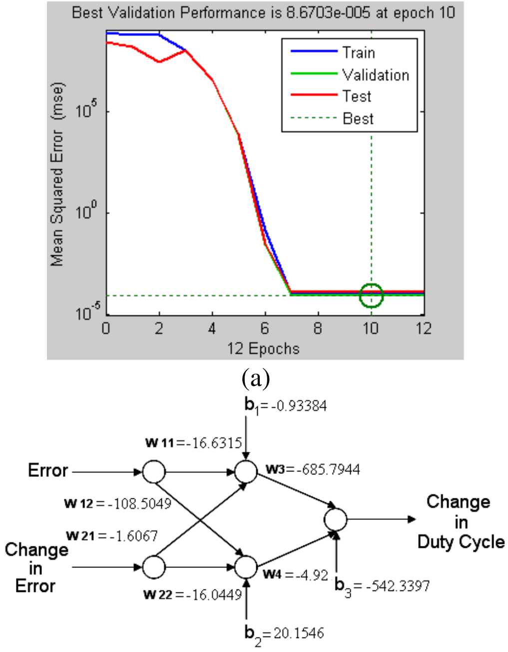
The ANN controller was trained with the training data obtained from conventional PID controller. The PID controller parameters were determined by Ziegler-Nichols method with MATLAB/Simulink. The PID-ANN controller is designed with few neurons and one hidden layer. The feed forward neural network is formed with two neurons in the input layer, three in the hidden layer and one neuron in the output layer. The error e(k) and change in error Δe(k) are the two inputs of the designed network and the neurons are biased properly. The pure linear activation function is used for input and hidden neurons, the tangent sigmoidal activation function for output neuron. A supervised feed forward back propagation neural network-training algorithm is used and it is trained with minimum error goal. The output of the network is change in the duty cycle Δdc(k). The designed ANN is trained with the error goal of 0.0067113 at 11 epochs.

The input of PID controller is error and the output is change in duty cycle. The ANN requires error and change in error as input parameter and the change in duty cycle as target parameter to train the neurons effectively. Therefore the change in error also was calculated from the error from the same simulation circuit. The conventional PID controller is simulated for 5 seconds with the sampling time of 0.0001seconds. Totally 50001 data were obtained from the drive system with PID controller. Out of 50001 only 1200 data were taken for training the ANN controller by removing the same value of data. Some of the sample data is given in Table 2.

Table 2. Sample Data from PID controller

Input Data	Error	1.0000	0.8573	0.7334	0.6271	0.5356	0.4572	0.3898
	Change in Error	-0.0005	-0.0004	-0.0004	-0.0003	-0.0003	-0.0002	-0.0002
Target Data	Corresponds to δ	200020	-19160	-10409	-4932	-7337	-6190.2	239.08

The PID-ANN is trained with lowest amount of error goal. The network is trained with the error goal of 0.000086703 in 10 epochs. The training and validation of ANN parameter during supervised back propagation training algorithm is graphically shown in Figure 4 (a). The trained network structure with layer weights and bias weights are shown in Figure 4(b). The complete flow diagram for the design of Hybrid PID-ANN controller is given in Figure 5.



(a)

(b)

Fig. 4 (a)ANN parameter variation during training, (b)Structure of Trained Neural network.

3.3. Simulation Results

The structure of the ANN controller using MATLAB simulink is shown in Figure 6. The simulation was done with MATLAB/Simulink for both the motor by changing the set speed and by changing the applied load torque. The Simulink model BLDC motor with PID-ANN controller was simulated using MATLAB/simulink toolbox and given in Figure 7. The duty cycle is getting from the PID-ANN controller and which is given to PWM unit. The PWM unit generates the pulse at 1 KHz of switching frequency. The current controller permits the pulse to the inverter if the motor current is below the reference current. Then the inverter gives the variable voltage to the motor depends on the PWM input to the inverter. There by the motor speed is controlled.

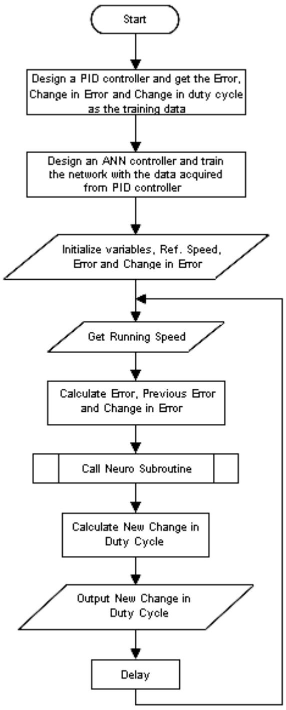


Fig 5. Flow Chart for the Hybrid PID-ANN controller

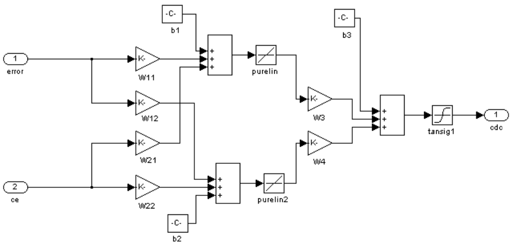


Fig.6. Structure of the ANN controller

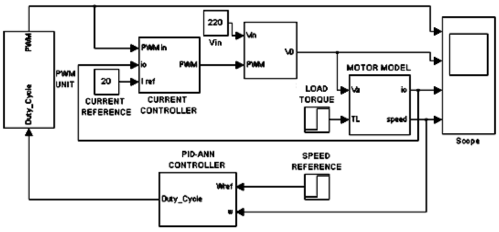
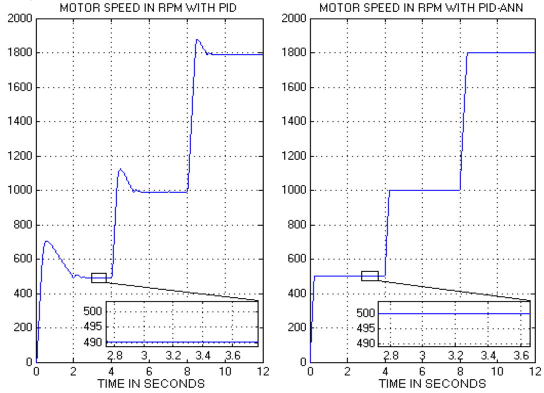


Figure 7 Simulink Model of the proposed system with ANN controller

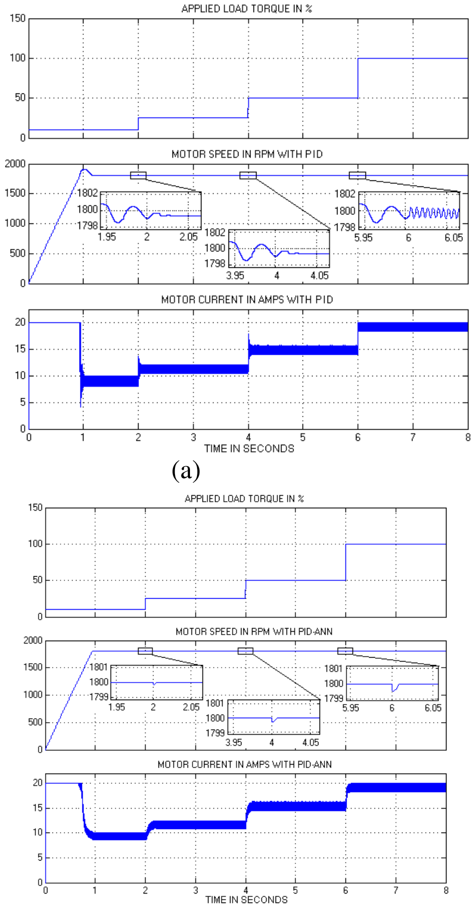
The Figure 8 shows the speed variation and for the step change in reference speed from 500rpm to 1000rpm at 4 seconds and 1000rpm to 1800rpm at 8 seconds with 10% load torque for PID controller and PID-ANN controller. From the Figure 8 the maximum over shoot is very large in PID controller it is due to the nature of PID controller where as in PID-ANN controller the maximum over shoot is completely reduced to zero. It is clearly seen in the fig 8 when the speed is increased from 500rpm to 1000rpm the motor takes 0.28 seconds whereas in the initial stage it took almost 0.30 seconds to reach 500rpm. This may be due to the inertia in the beginning. The PID-ANN controller provides accurate seed regulation for all the speed changes compared to conventional PID controller.

The simulated result of speed regulation for a step change in the load torque from 10% to 25%, 25% to 50% and 50% to 100% applied at 2 seconds, 4 seconds and 6 seconds are shown in Figure 9. During each load changes there is a small amount of dip in the speed response and it regains the original speed very quickly. At 25% load the speed drop is 0.005% it is very less and may be neglected and it is regain the speed with in 0.002 seconds. The PID-ANN controller provides very good response to the system for the load changes from 10% to 100%.



(a) (b)

Fig 8. Speed Variation at 2 sec, 4sec and at 8sec with 10% Load Torque (a) PID controller (b) PID-ANN controller



(b)

Fig 9. Load variation at 2sec, 4sec and 6sec with rated speed (a) PID controller (b)PID-ANN controller

The comparative transient and dynamic performance of the motor with speed variation for various loads are depicted in Table 3. It can be clearly seen from the Table 3 the steady state error is zero for all the load changes. However the recovery time and maximum speed drop of PID-ANN controller is almost very less compared with the PID. It is absorbed from the table 3 and 4 the performance of the proposed PID-ANN controller is better for the transient and dynamic performance compared with PID controller.

Table 3. The Transient and dynamic performance of the BLDC motor for speed changes with PID and PID-ANN controller

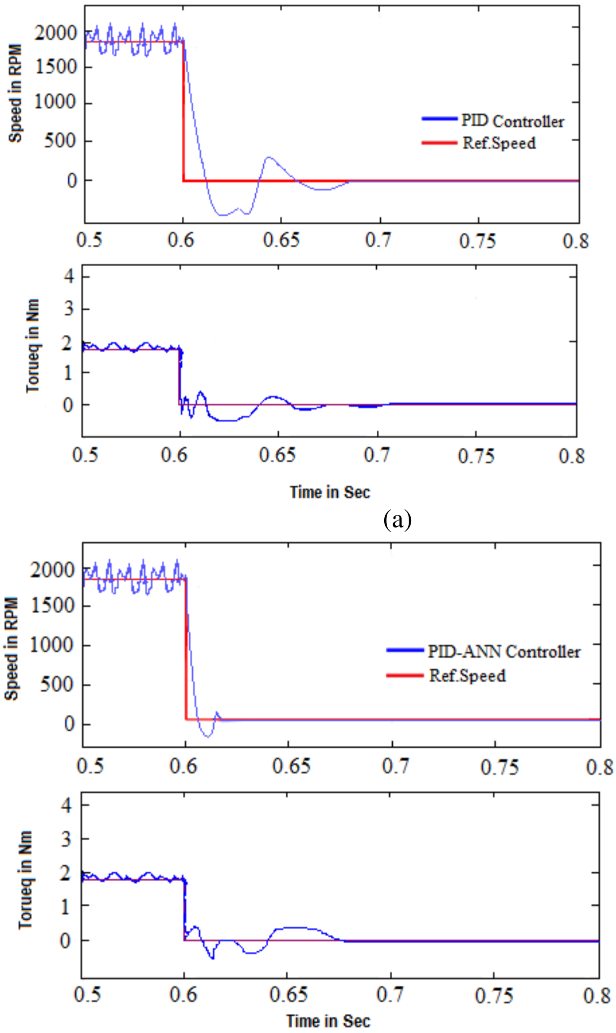
Set Speed Changes	0 to 500RPM		500 to 1000RPM		1000 to 1800RPM	
	PID	PID ANN	PID	PID ANN	PID	PID ANN
Max. over Shoot in %	10.49	0.99	10.68	0.82	10.33	0.61
Settling time in Sec.	4.3	0.28	3.6	0.2	3.99	0.24
Rise Time in Sec.	1.26	0.49	1.32	0.51	1.3	0.4
Steady State Error in RPM	+22	0	+22	0	+23	0

3.3.1 Fault Analysis of the BLDC motor with PID ANN controller

The fault analysis of the motor has been done with two methods [9]. First one is one phase Open Circuit Fault (OCF) and another one is phase to phase Short Circuit Fault (SCF) methods. The OCF and SCF are illustrated in fig 1. The OCF occurs in any one of the 3 phases in the BLDC motor terminal under motor running in normal operating condition. The under the OCF condition the motor speed and torque performance is clearly shown in the fig 10 with controller. The controller is also used to product the motor under fault condition. The phase sensors are used to find the fault under motor normal operating condition. The motor under fault condition, the controller is discontinuing the inverter output to the motor and the motor speed is suddenly reduced.

An OCF applied in the motor on 0.6 sec and it is shown in the fig 10. It is clearly seen fin the fig 10, the PID ANN controller is reached the zero speed quickly after the fault condition compared to the conventional controller. The system oscillation is more in the conventional controller while in the fault condition. It is observed from the fig 10(b) the speed and torque curves contains less ripples and motor have a small amount of inertia J= 0.5 X 10^{-6} . Due to this motor low inertia the motor speed is shows quick reaction to the dynamic torque decay.

The SCF occur in the motor on 0.6 sec under running normal condition and speed and torque response is shown in fig.11. The two phases A ,B are short circuit from the theoretical operation. The motor attain in the zero torque region, the rotor is going to drop the driving torque and the discontinued the running speed quickly because of the low inertia and load damping. It is seen in the fig 11 (b) the speed and torque curves are smooth and less ripples present in the SCF. The motor speed reaches the zero speed position in quick time using the proposed controller. The motor under in the initial fault condition there is a small amount of dip in the speed response and it regains the zero speed very quickly. The PID-ANN controller provides very good response to the system for the motor in the fault condition. The controller performance under fault condition as tabulated in table.5. It is concluded from the table the proposed controller is operated in better manner in all conditions compared to the conventional controllers.



(a)

(b)

Fig 10 Speed and Torque response under OCF (a) PID controller (b) PID ANN controller

Table 4. The Transient and dynamic performance of the BLDC motor for load changes with PID and PID-ANN controller

Load Changes	10% to 25%		25% to 50%		50% to 100%	
	PID	PID ANN	PID	PID ANN	PID	PID ANN
Max. Speed Drop in %	1.8	0.21	1.86	0.27	2.7	0.24
Recovery time in Sec.	0.25	0.015	0.3	0.019	N/A	0.01
Settling time in Sec.	5.29	0.2	5.19	0.199	5.2	0.1
Rise Time in Sec.	1.56	0.35	1.4	0.41	1.48	0.39
Steady State Error in RPM	+15	±10	+20	±9	+50	±3.3

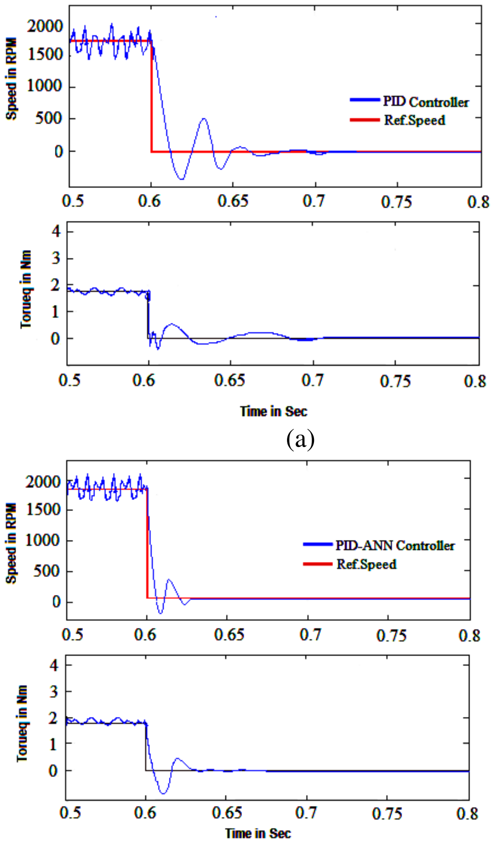


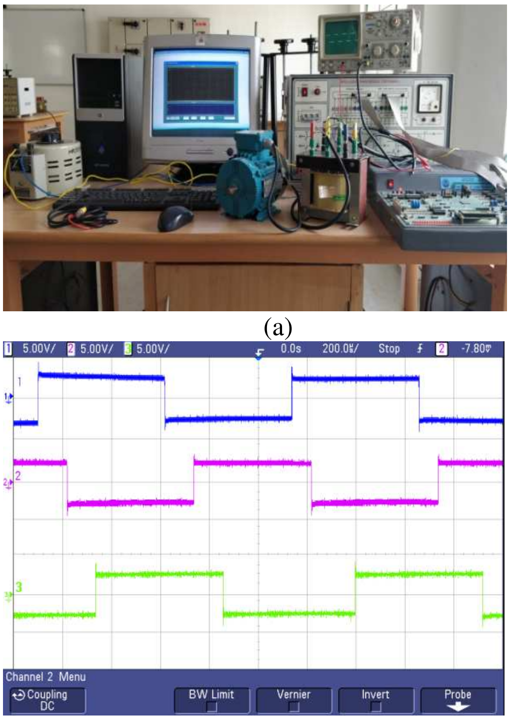
Fig 11 Speed and Torque response under SCF (a) PID controller (b) PID ANN controller

Table .5 Performance of the Controller under fault condition

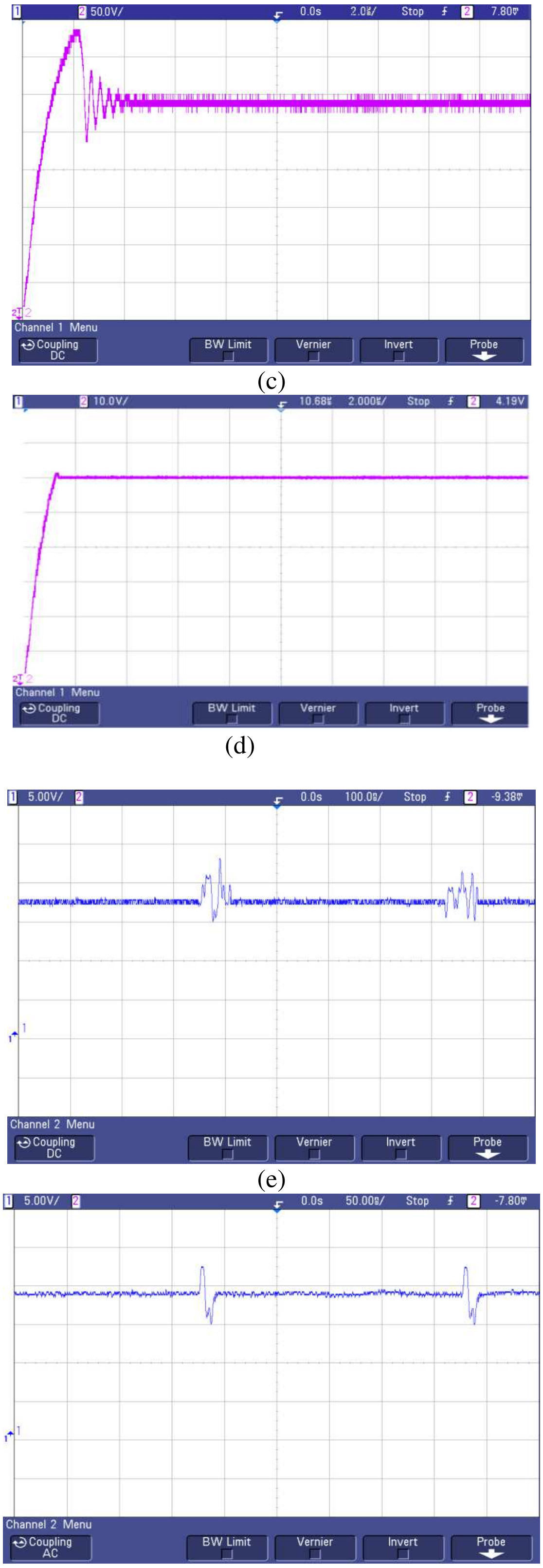
Parameters Controller	PID	PID-ANN
Toque in Nm	8.02	5.92
Torque ripple coefficient (T_t)	0.0692	0.03
% Overshoot	2.5	0.86
Settling Time in Sec.	0.55	0.2
Peak Time	0.528	0.260

4. Experimental Setup

The proposed system is implemented by using a TMS320F240 DSP processor. The inverter is built with the MOSFET using IRFP840, and the controllers were tested with 300W, 50 Hz BLDC motor. The generation of the PWM at a range of the frequency is 5kHz. The LTS25NP current sensor is used to sense the BLDC motor current and compare with reference current. The LM 399 comparator is used for the current comparison. The reference current is more than the actual current, the PWM signal is given to the inverter using AND gate. The speed of the motor can be controlled from inverter output. GP1L53V digital pulse type sensor is used to sense the BLDC motor speed. LM2907 IC is received the PWM signal and ADC IC ADC0808CCN receive the feedback control signal from the microcontroller. The experimental setup is shown in the fig. 12 (a). The motor output is sensed by the hall sensor and it's shown in fig 12 (b). The BLDC motor with rated speed with PID and PID ANN controller is shown in fig 12 (c) and (d) respectively. It is clearly shown in the waveform the settling time and peak over shoot of the motor is high while using the PID controller based system. The PID ANN controller is reduced the overshoot, steady state error and settling time of the BLDC motor.



(b)



(c)

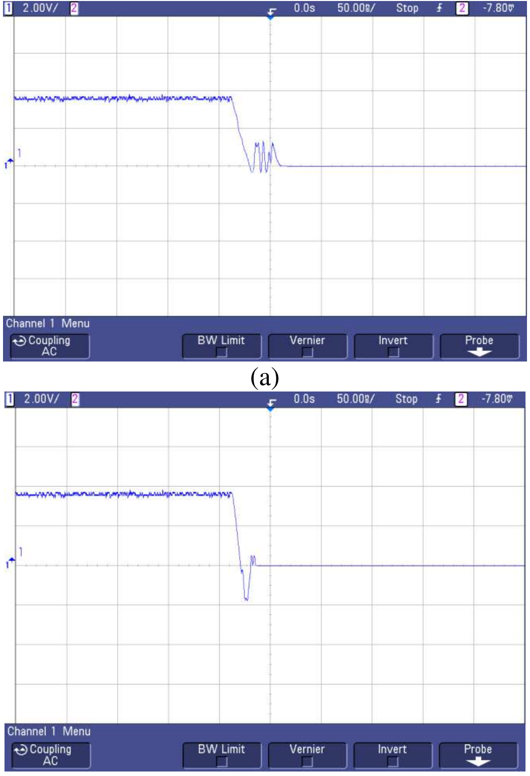
(d)

(e)

(f)

Fig 12. Experimental waveforms for (a) Experimental setup (b) hall sensor output of the motor (c) motor speed using PID controller (d) motor speed using PID ANN (e) Load variation at 4sec and 6sec with rated speed (e) PID controller (d) PID ANN controller

The motor is running in under normal condition the load variation is obtained in 4 sec and 6 sec. the motor performance under in load condition is shown in fig 12 (e) and (f) with different controllers. The proposed controller is performed in better manner and reached the steady state value quickly compared to the PID controller. The motor under OCF and SCF condition are obtain in normal running condition and the motor speed performance is shown in fig 13.(OCF) and (SCF).



(a)

(b)

Fig 13. Motor under fault Condition (a)OCF (b)SCF

In the OCF condition the motor operated in 4 V and damping load is 0.01 N.m.s used and the fault obtained in phase A in the time of 4 sec. it clearly absorbed from the fig 13 (a) the speed curvature contains less ripple and no skew effect is measured. The phase current A attains the zero and the high spike voltage is occurred due to the OCF condition. The phase current B and C of the motor terminals are short circuited and the fault is take place in the time of 4 sec as shown in fig 13 (b). Due to the SCF effect the driving torque dropped from the rotor and the motor speed reached zero quickly. The fig 13 (b) absorbed the small drop in the 4 sec because of the damping load and small inertia.

It is clearly seen in the table 6 the proposed controller performance is better in transient and steady state conditions compared to the conventional controller. The percentage overshoot of the motor is 0.001 while using in the PID ANN controller. It is observed from the table 6 the motor power is dropped due to the heavy load changes in the PID controller and PID ANN controller it is power maintained in steady state value while changed in load condition.

Table 6. Performance analysis of the BLDC motor in experimental studies

Controller	PID	PID-ANN
During rated speed and 10% load		
Rise time in seconds	1.89	0.61
Settling time in Seconds	3.9	0.86
Max. over Shoot in %	8.65	0.001
Steady state error in rpm	+20	0
Set Speed Change from 1000 to 1800rpm		
Max. over Shoot in %	2.35	0.001
Settling time in Sec.	2.51	0.9
Load Change from 50% to 100%		
Max. Speed Drop in %	3.37	0.05
Recovery time in Seconds	0.92	0.001
Steady State Error in rpm	+20	0

5. Conclusion

The state space model of the BLDC motor has been developed and estimating the performance of the motor has been analyzed with stability and fault analysis. The proposed PID ANN controller has been analyzed and estimated with simulink/MATLAB. The state plan and Lyapunov Technique used to found and concluded that the proposed system is stable in all conditions. It has been concluded form the analysis proposed controller provides better performance in transient and dynamic conditions. The PID ANN controller performance has been analyzed in speed and load variation. Also the OCF and SCF condition of the motor has been estimated and presented. The proposed PID ANN controller provides a better speed tracking without a smaller amount of settling time and minimum over shoot. The experimental setup was designed and the results are closely matched with simulation results.

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