Improve the Performance of Intelligent PI Controller for Speed Control of SEDM using MATLAB

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Abstract–In this paper a new approach is develop for speed control of separately excited D.C. motor by enhancing the feature of artificial neural networks (ANN).The development of artificial Neural Network controller for D.C. drives is inspired by the ANN control strategy. The aim of the proposed schemes is to improve dynamic performance of separately excited D.C. motor [6]. The ANN concept is applied for both control strategy i.e. current and speed for D.C. separately excited motor. This new concept enhances the performance and dynamics of D.C. motor in comparison to conventional PI controllers and this is verified through simulation using MATLAB/SIMULINK.

Keywords–DC motor, ANN, PI controller, NARMA-L2 controller

I. INTRODUCTION

The separately excited Direct current (DC) motors with conventional Proportional Integral (PI) speed controller are generally used in industry. This can be easily implemented and are found to be highly effective if the load changes are small. However, in certain applications, like rolling mill drives or machine tools, where the system parameters vary substantially and conventional PI or PID controller is not preferable due to the fact that, the drive operates under a wide range of changing load characteristics.

The artificial neural network (ANN), often called the neural network, is the most generic form of Artificial Intelligence for emulating the human thinking process compared to the rule-based Expert system and Fuzzy Logic [2]. Multilayer neural networks have been applied in the identification and control of dynamic systems. The three typical commonly used neural network controllers: model predictive control, NARMA-L2 control, and model reference control are representative of the variety of common ways in which multilayer networks are used in control systems. As with most neural controllers, they are based on standard linear control architectures [3].There are a number of articles that use ANNs applications to identify the mathematical D.C. motor model and then this model is applied to control the motor speed [4]. They also use inverting forward ANN with input parameters for adaptive control of D.C. motor [5].

This paper address the study of steady-state and dynamics control of dc machines supplied from power converters and their integration to the load. This paper a comparative study of artificial neural networks over conventional controller such as PI speed and current controller. With the help of transfer function models, analysis of the performance of the dc motor drives for different cases has been done.

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II. TWO-QUADRANT THREE-PHASE CONVERTER CONTROLLED DC MOTOR DRIVE

The control schematic of a two converter controlled separately excited dc motor is shown in Fig.1. The thyristor bridge converter gets its ac supply through a three phase transformer and fast acting ac contactors. The field is separately excited, and the field supply cannot be kept constant or regulated. The DC motor has a tacho-generator whose output is utilized for closing the speed loops. The motor is driving a load considered to be frictional for this treatment. The output of the tacho-generator is filtered to remove the ripples to provide the signal, ω_{mr}. The speed command and ω_r* is compared to the speed signal to produce a speed error signal. This signal is processed through a proportional plus integrator (PI) controlled to determine the torque command. The torque command is limited, to keep it within the safe current limits. The armature current command i_a* is compared to the actual armature current i_a to have a zero current error. In case, there is an error, a PI current controller process it to alter the control signal v_c. The control signal accordingly modifies the triggering angle α to be sent to the converter for implementation [2]. The operation of closed speed controlled drive is explained from one or two particular instances of speed command. A speed from zero to rated value is commanded, and the motor is assumed to be at standstill, this will generate a large speed error and a torque command and in turn an armature current command. The armature current error will generate the triggering angle to supply a preset maximum dc voltage across the motor terminals.

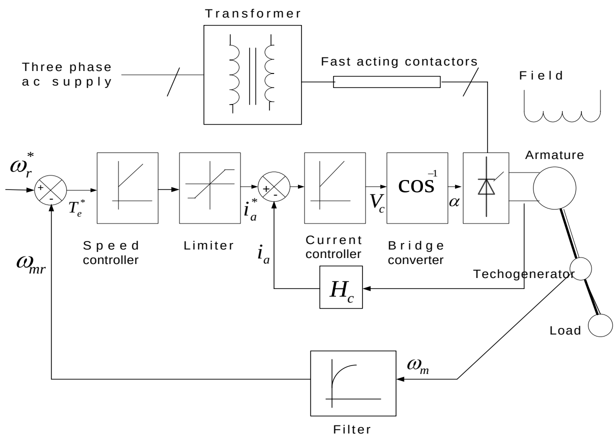

Fig.1: Speed –controlled two quadrant dc motor drive

The inner current loop will maintain the current at level permitted by its commanded value. When the rotor attains the commanded value, the torque command will settle down to a value equal to the sum of load torque and other motor losses to keep the motor in steady state. The design of the gain and time constant of the speed and current controllers is of paramount importance in meeting the dynamic specifications of the motor drives.

III. MODELING AND DESIGN OF SUBSYSTEMS

A. DC motor and load

The dc machine contains an inner loop due to the induced emf. It is not physically seen; it is magnetically coupled. The inner current loop will cross this back-emf loop, creating a complexity in the development of the model. The development of such a block diagram for the dc machine is shown in Fig.2. The load is assumed to be proportional to speed and is given as

$$T_l = B_l \omega_m \tag{1}$$

To decouple the inner current loop from the machine-inherent induced-emf loop, it is necessary to split the transfer function between the speed and voltage into two cascade transfer functions, first between speed and armature current and then between armature current and input voltage, represented as

$$\frac{\omega_m(s)}{V_a(s)} = \frac{\omega_m(s)}{I_a(s)} \cdot \frac{I_a(s)}{V_a(s)} \tag{2}$$

$$\frac{\omega_m(s)}{I_a(s)} = \frac{K_b}{B_t(1+sT_m)} \tag{3}$$

$$\frac{I_a(s)}{V_a(s)} = K_1 \frac{(1+sT_m)}{(1+sT_1)(1+sT_2)} \tag{4}$$

$$T_m = \frac{J}{B_t} \tag{5}$$

$$B_t = B_1 + B_l \tag{6}$$

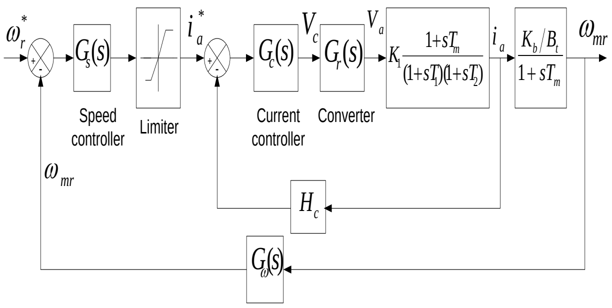

Fig.2: Block diagram of the motor drive

$$-\frac{1}{T_1}, \frac{1}{T_2} = -\frac{1}{2}\left[\frac{B_t}{J} + \frac{B_a}{L_a}\right] \pm \sqrt{\frac{1}{4}\left(\frac{B_t}{J} + \frac{B_a}{L_a}\right)^2 - \left(\frac{K_b^2 + R_a B_t}{J L_a}\right)} \tag{7}$$

$$K_1 = \frac{B_t}{K_b^2} + R_a R_t \tag{8}$$

B. Design of Controllers

The design of control loops starts from the innermost (fastest) loop and proceeds to the slowest loop, which in this case is the outer speed loop. The reason to proceed from the inner to the outer loop in the design process is that the gain and time constants of only one controller at a time are solved. Instead of solving for the gain and time constants of all the controllers simultaneously not only that is logical; it also has a practical implication. Note that every motor drive need not be speed controlled but may be torque-controlled, such as for a traction application. In that case, the current loop is essential and exists regardless of whether the speed loop is going to be closed. Additionally, the performance of the outer loop is dependent on the inner loop; therefore, the tuning of the inner loop has to precede the design and tuning of the outer loop.

a. Current Controller

The current control loop is shown in Fig.3. the loop gain function is

$$GH_i(s) = \frac{K_1 K_c K_r H_c}{T_c} \cdot \frac{(1+sT_c)(1+sT_m)}{s(1+sT_1)(1+sT_2)(1+sT_r)} \tag{9}$$

This is a fourth-order system, and simplification is necessary to synthesize a controller without resorting to a computer. Noting that T_m is on the order of a second and in the vicinity of the gain crossover frequency, we see that the following approximation is valid:

$$(1+sT_m) \cong sT_m \tag{10}$$

this reduces the loop gain function to

$$GH_i(s) = K \cdot \frac{(1+sT_c)}{(1+sT_1)(1+sT_2)(1+sT_r)} \tag{11}$$

where

$$K = \frac{K_1 K_c K_r H_c T_m}{T_c} \tag{12}$$

the time constants in the denominator are seen to have the relationship

$$T_r < T_2 < T_1 \tag{13}$$

The equation (11) can be reduced to second order, to facilitate a simple controller synthesis, by judiciously selecting

$$T_c = T_2 \tag{14}$$

Then the loop function is

$$GH_i(s) = \frac{K}{(1+sT_1)(1+sT_r)} \tag{15}$$

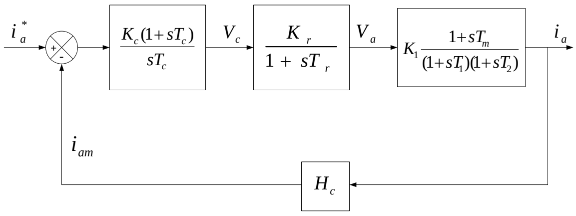

Fig. 3: Current control loop

The characteristic equation or denominator of the transfer function between the armature current and its command is

$$(1+sT_1)(1+sT_r)+K \tag{16}$$

this equation is expressed in standard form as

$$T_1T_r\left\{s^2 + s\left(\frac{T_1+T_2}{T_1T_r}\right)+\frac{K+1}{T_1T_r}\right\} \tag{17}$$

From which the neural frequency and damping ratio are obtained as

$$\omega_n^2 = \frac{K+1}{T_1T_r} \tag{18}$$

$$\varsigma = \frac{\frac{T_1+T_r}{T_1T_r}}{2\sqrt{\frac{K+1}{T_1T_r}}} \tag{19}$$

where ω_n and ς are the natural frequency and damping ratio, respectively. For good dynamic performance, it is an accepted practice to have a damping of 0.707.Hence, equating the damping ratio to 0.707 in equation (19), we get

$$K+1 = \frac{\left(\frac{T_1+T_r}{T_1T_r}\right)^2}{\frac{2}{T_1T_r}} \tag{20}$$

Realizing that

$$K \gg 1 \tag{21}$$

$$T_1 \gg T_r \tag{22}$$

Tells us that K is approximated as

$$K \cong \frac{T_1^2}{2T_1T_r} \cong \frac{T_1}{2T_r} \tag{23}$$

by equating equation (12) to (23).the current-controller gain is evaluated

$$K_c = \frac{1}{2}\frac{T_1T_c}{T_r}\left(\frac{1}{K_1K_rH_cT_m}\right) \tag{24}$$

b. Speed Controller

The speed loop with the first-order approximation of the current-control loop is shown in Fig.4.The loop gain function is

$$GH_s(s) = \frac{K_sK_iK_bH_w}{B_tT_s}\cdot\frac{(1+sT_s)}{s(1+sT_1)(1+sT_m)(1+sT_\omega)} \tag{25}$$

This is a fourth-order system. To reduce the order of the system for analytical design of the speed controller, approximation serves. In the vicinity of the gain crossover frequency, the following is valid

$$(1+sT_m) = sT_m \tag{26}$$

The next approximation is to build the equivalent time delay of the speed feedback filter and current loop. Their sum is very much less than the integrator time constant T_s and hence the equivalent time delay, T_4 can be considered the sum of the two delays, T_i and $T\omega$. This step is very similar to the equivalent time delay introduced in the simplification of the current loop transfer function.Hence, the approximate gain function of the speed loop is

$$GH_s(s) \cong K_2\frac{K_s}{T_s}\frac{(1+sT_s)}{s^2(1+sT_4)} \tag{27}$$

where

$$T_4 = T_i + T_\omega \tag{28}$$

$$K_2 = \frac{K_iK_bH_\omega}{B_tT_m} \tag{29}$$

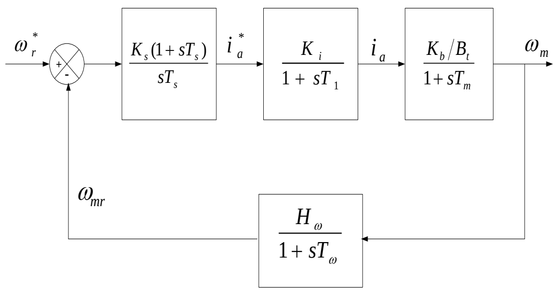

Fig.4: Representation of the outer speed loop in the dc motor drive

The closed loop transfer function of speed to its command is

$$\frac{\omega_m(s)}{\omega_r^*(s)} = \frac{1}{H_\omega}\left[\frac{\frac{K_2K_s}{T_s}(1+sT_s)}{s^3T_4+s^2K_2K_s+\frac{K_2K_2}{T_s}}\right] = \frac{1}{H_\omega}\frac{(a_0+a_1)}{(a_0+a_1s+a_2s^2+a_3s^3)} \tag{30}$$

where

$$a_0 = K_2K_s/T_s \tag{31}$$

$$a_2 = K_2 K_s \tag{32}$$

$$a_2 = 1 \tag{33}$$

$$a_3 = T_4 \tag{34}$$

This transfer function is optimized to have a wider bandwidth and a magnitude of one over a wide frequency range by looking at its frequency response. Its magnitude is given by

$$\left|\frac{\omega_m(j\omega)}{\omega_r^*(j\omega)}\right| = \frac{1}{H_\omega}\sqrt{\frac{a_0^2+\omega^2 a_1^2}{\{a_0^2+\omega^2(a_1^2-2a_0a_2)+\omega^4(a_2^2-2a_1a_3+\omega^6 a_3^2)+\omega^6 a_3^2\}}} \tag{35}$$

This is optimized by making the coefficients ω^2 and ω^4 equal to zero, to yield the following conditions

$$a_1^2 = 2a_0 a_2 \tag{36}$$

$$a_2^2 = 2a_1 a_3 \tag{37}$$

Substituting these conditions in terms of the motor and controller parameters given in (31) into (34) yields

$$T_s^2 = \frac{2T_s}{K_s K_2} \tag{38}$$

Resulting in

$$T_s K_s = \frac{2}{K_2} \tag{39}$$

Similarly

$$\frac{T_s^2 s}{K_s^2 K_2^2} = \frac{2T_s^2 T_4}{K_s K_2} \tag{40}$$

Thus after simplification, gives the speed – controller gain as

$$K_s = \frac{1}{2K_2 T_4} \tag{41}$$

Substituting equation (41) into equation (39) gives the time constant of the speed controller as

$$T_s = 4T_4 \tag{42}$$

Substituting for K_s and T_s into equation (38) gives the closed-loop transfer function of the speed to its command as

$$\frac{\omega_m(s)}{\omega_m^*(s)} = \frac{1}{H_\omega}\left[\frac{1+4T_4 s}{1+4T_4 s+8T_4^2 s^2+8T_4^2 s^2+8T_4^3 s^3}\right] \tag{43}$$

It is easy to prove that for the open-loop gain function the corner points are$1/4T_4$ and $1/T_4$, with the gain crossover frequency being $1/2T_4$.

IV. NARMA-L2 CONTROL

The central idea of this type of control is to transform nonlinear system dynamics into linear dynamics by canceling the nonlinearities. This section begins by presenting the companion form system model and demonstrating how you can use a neural network to identify this model [11]. Then it describes how the identified neural network model can be used to develop a controller. The tapped delay line (TDL), to make full use of the linear network. There the input signals enter from the left and passes through N-1 delays. The output of the tapped delay line (TDL) is an N-dimensional vector, made up of the input signal at the current time, the previous input signal. Using the NARMA-L2 model, you can obtain the controller.

$$u(k+1) = \frac{y_r(k+d) - f[y(k),\cdots,y(k-n+1),u(k),\cdots,u(k-n+1)}{g\left[y(k),\cdots,y(k-n+1),u(k),\cdots,u(k-m+1)\right]} \tag{44}$$

which is realizable for $d \geq 2$.

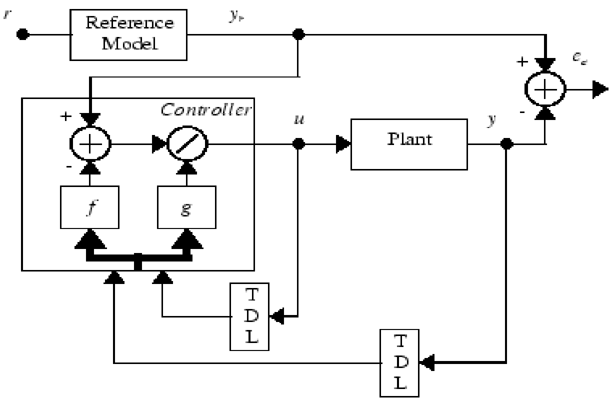

Fig.5: Block diagram of the NARMA-L2 controller

This controller can be implemented with the identified NARMA-L2 plant model, as shown in the Fig.6.

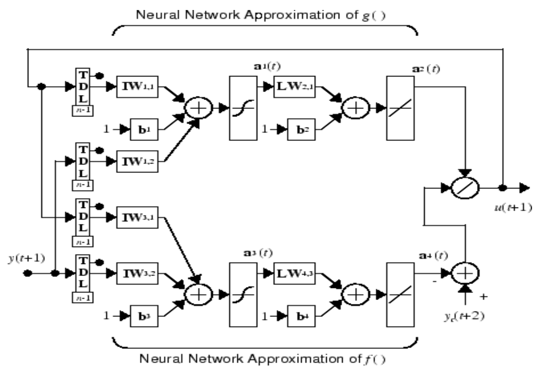

Fig. 6: Identified NARMA-L2 plant model

V. SIMULINK MODEL AND RESULTS

A. Response of the system using current and speed control strategy with conventional PI controller

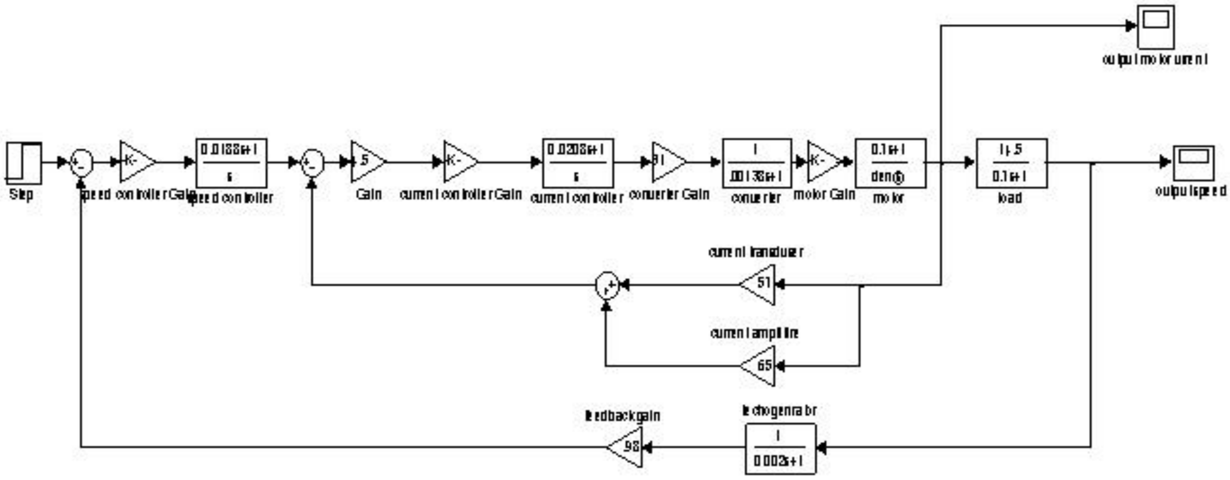

Fig.7: Simulink plant model with speed and current controller

In this control strategy, current control and speed control are applying for improving the performance of DC motor drive. In Fig.7.Shows the simulation plant model for this case. The responses are shown in Fig.8(a) and 8(b).

B. Control strategy with ANN controller (NARMA-L2 CONTROL)

In this text consider the simulink modeling of a separately excited DC motor with speed and current controller using ANN. The entire conventional PI controller is replaced by ANN. The control system of DC motor using neural networks is presented. In this case study where use the either single neural network as a controller for the control the speed of DC drive with using Both control strategy. The performance of DC motor drive with ANN controller is evaluated by simulink plant model. The plant input and output data are generated by neural network tools of MATLAB/SIMULINK for training of neural networks. The control signal for converters according to plant output is generated by trained ANN on the basis of plant identification. In this study use the different type of cases are as follows:

a. Using only current controller
b. Using only speed controller
c. Single ANN controller with both current and speed control

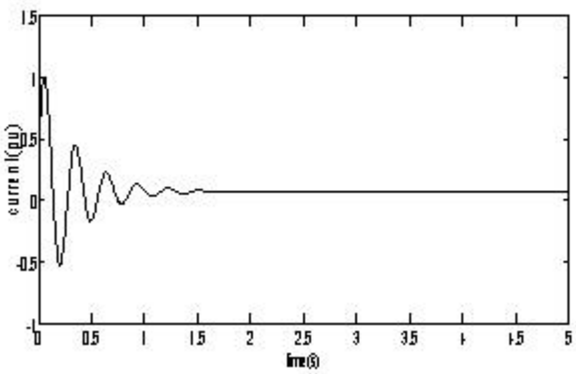

Fig.8 (a): Output motor current response

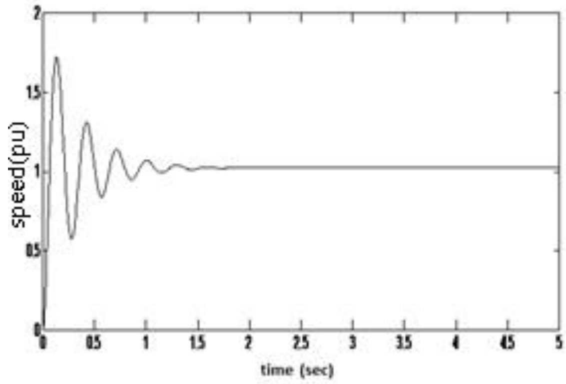

Fig.8 (b): Output motor speed response

a. Response of system using only current control strategy with ANN:

In this case reference plant have only current controller, shown in Fig.10.The input and output data are generated by this reference plant which is shown in Fig.12.The complete plant layout is given in Fig.9.The neural network specification are shown in Fig.11.The response of the system with simulink plant model with ANN, using current control strategy is shown in Fig.13.The result shows that the response of the system is better than using conventional PI controller.

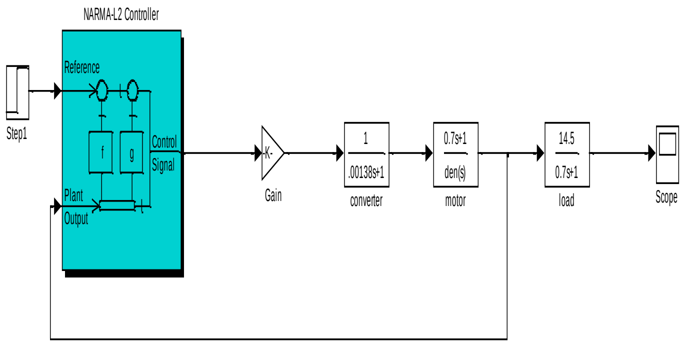

Fig.9: Simulink plant model using only current control strategy with ANN

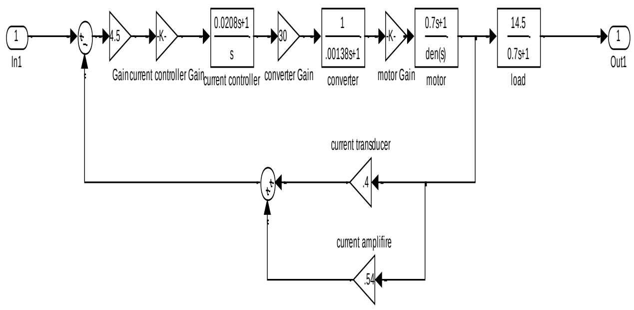

Fig.10: Simulink reference plant model for training of ANN with current controller

b. Response of the system using only speed control strategy with ANN:

In this case plant layout is shown in Fig.14. Only change the plant specification of ANN and reference plant model which is shown in Fig.15&16. The input and output data are generated by this reference plant which is shown in Fig.17.The response of the system with simulink plant model with ANN, using speed control strategy is shown in Fig.18.The results show that the response of the system is not so poor but the settling time is more in comparison to (a).

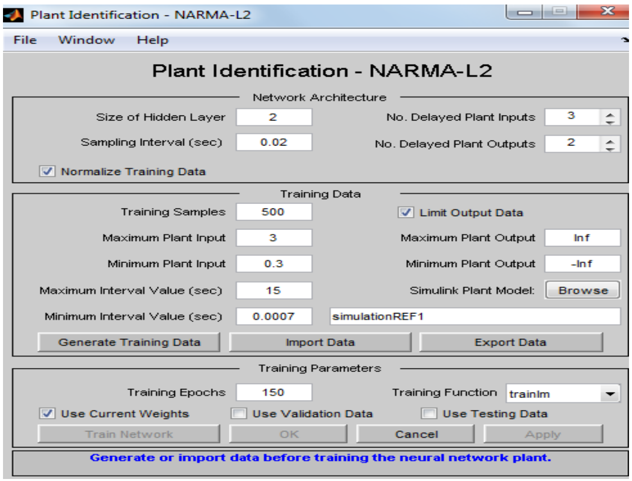

Fig.11: ANN and Plant specification model with only current control strategy

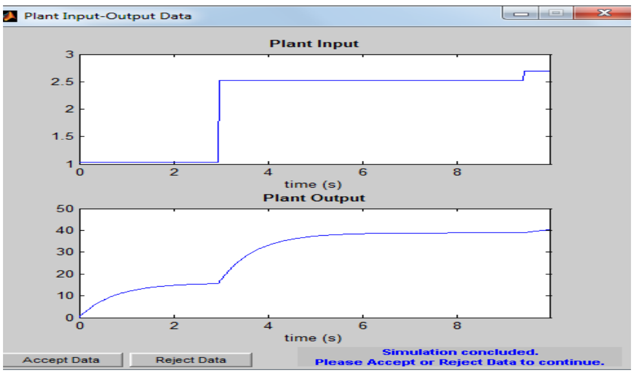

Fig.12: Plant input and output generated by reference plant for ANN

c. Response of system using speed and current control with ANN:

In this case only single neural network is used for both speed and current control strategy which is shown in Fig.19. Reference model for training of ANN with current and speed controller is shown in Fig.20. The plant specification and plant input output model with both current and speed control strategy is shown in Fig.21 and 22. The response of the system is shown in Fig.23. The result of this system shows that the response of the plant is so better in comparison to previous cases as well as conventional PI control methods.

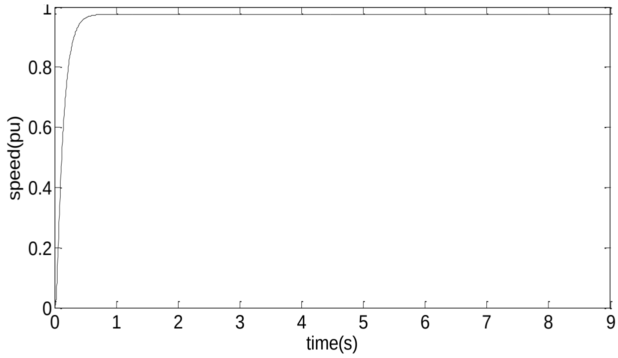

Fig.13: Plant output with current control strategy using ANN as current controller

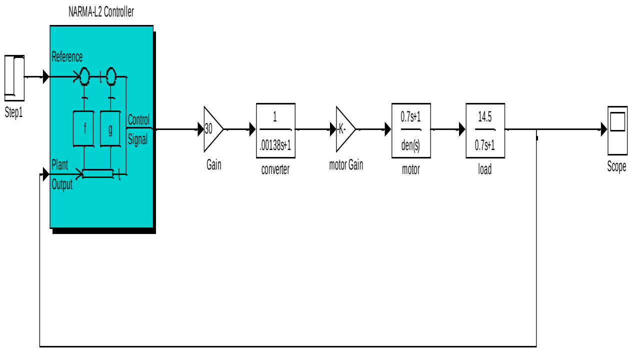

Fig.14: Simulink plant model using only speed control strategy with ANN

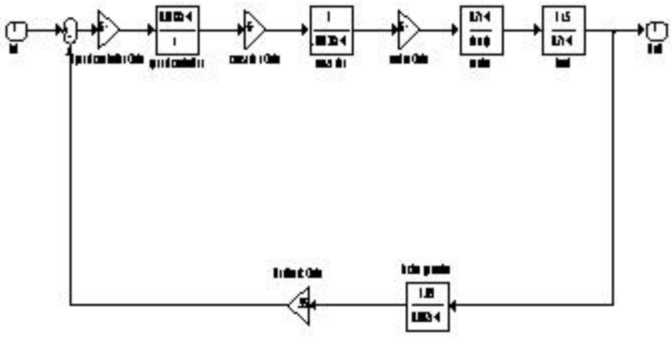

Fig.15: Simulink reference model for training of ANN with speed controller

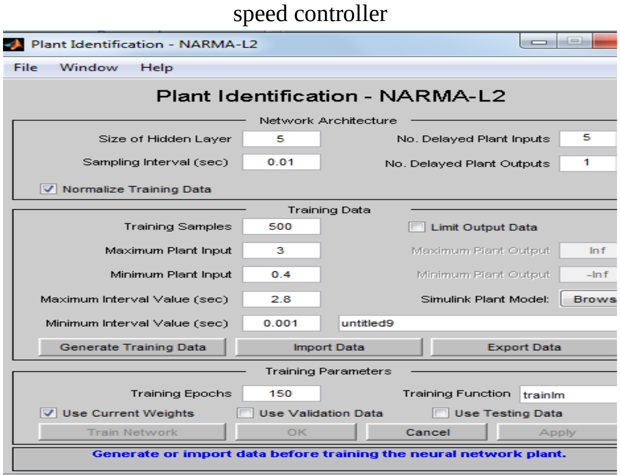

Fig.16: ANN and plant specification model with only speed control strategy

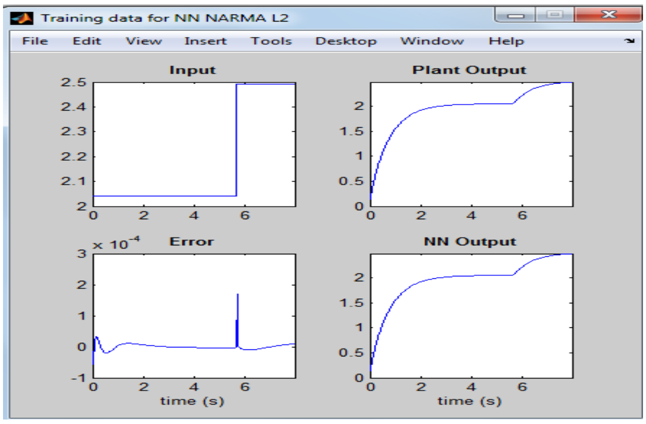

Fig.17: Plant input and output generated by reference plant for ANN

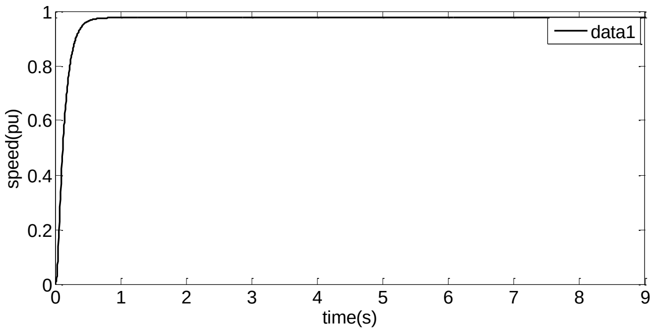

Fig.18: Plant output speed control strategy using ANN as speed controller

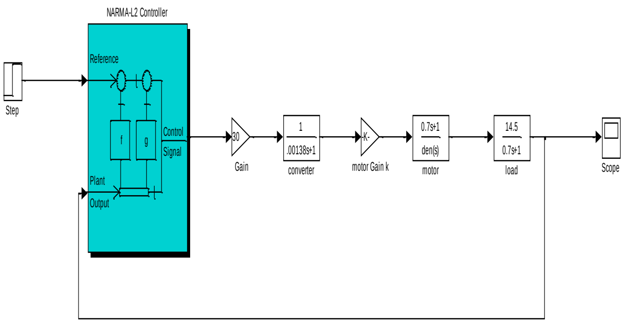

Fig.19: Simulink plant model with current and speed control using ANN

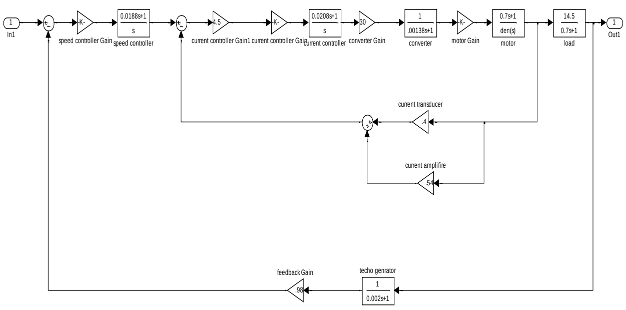

Fig.20: Simulink reference model for training of ANN with current and speed controller both

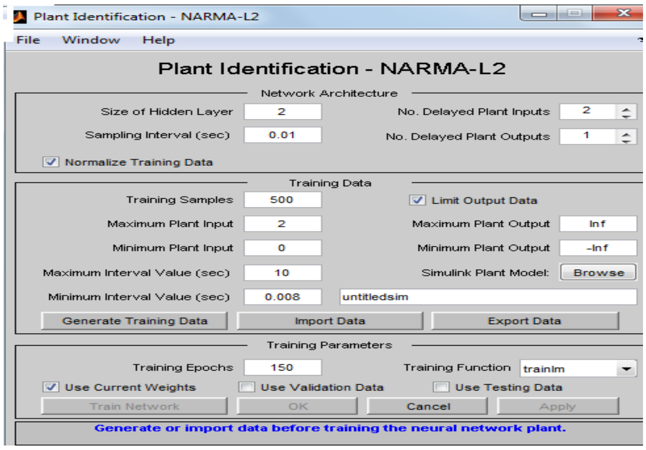

Fig.21: ANN and plant specification model with current and speed control strategy

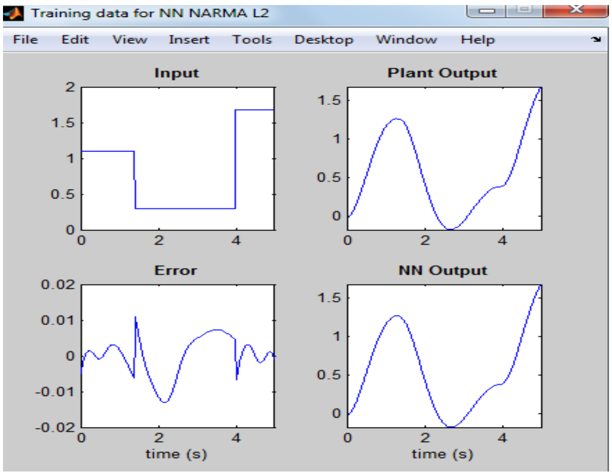

Fig.22: Plant input, output and ANN training error

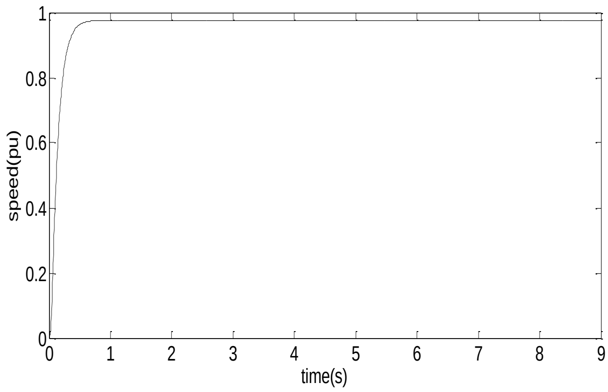

Fig.23: Plant output with current and speed control strategy using single ANN

VI. Results and Discussion

In this work actually evaluated the performance of a dc motor with a constant load using different type of control strategy conventional (PI) and modern (ANN) controller concept. Using the ANN controller concept with dc motor the performance and dynamics of the dc motor is improved in comparison to the conventional PI controllers. The simulation of the complete drive system is carried out based on training for different reference plant with different control strategy. The D.C. motor has been successfully controlled using an ANN. Firstly, one ANN controller is used with only Current control strategy. The results with both speed and current control strategy are better as compared to the results obtained with only current control and speed control strategy. The simulation result (Fig.23) shows that the response of the plant with both current and speed controller is better as compared to conventional methods (Table 1). The results prove that the complete D.C. drive system is robust to parameter variations. All the comparisons for the different cases are tabulated in Table 1.

Table 1: speed response

Cases		Settling time t_s (sec.)	Maximum overshoot (mp) p.u.	Steady state error (p.u.)
(A) Conventional control (PI)	For speed	1.8	1.7	0.02
	For current	1.7	1.0	0.03
(B) Modern control (ANN)	I	0.85	No overshoot	0.03
	II	0.95	No overshoot	0.04
	III	0.74	No overshoot	0.02

VII. CONCLUSION

By using ANN mode controller for the separately excited DC motor speed control, the following advantages have been realized.

The speed response for constant load torque shows the ability of the drive to instantaneously reject the perturbation. The design of controller is highly simplified by using a cascade structure for independent control of flux and torque. By using ANN don't have to calculate the parameters of the motor when designing the system control. By using ANN the complete D.C. drive system is robust to parameters variations. The dynamic and steady state performance of the ANN based control drive is much better than the PI controlled drives. Settling time has been reduced to a label of 0.0.74 sec.

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APPENDIX

The following motor parameters and ratings are used for designing speed-controlled dc motor drives, maintaining the field flux constant.

Power rating = 5*HP*,
D.C. motor input voltage = 220*V*,
Armature current rating = 8.2*A*,
Rated speed = 1470 rpm,
Armature resistance *Ra* = 4 *Ω*,
Moment of inertia *J* = 0.0609 $kg\text{-}m^2$,
Armature Inductance *La* = 0.074*H*,
Viscous friction coefficient *Bt* = 0.0867 *Nms/rad*,
Torque constant *Kb* = 1.23 *V/rad/s*.
Converter Supplied voltage = 230 *V*,
3 – Phase, A.C. Frequency = 50 *Hz*,
Maximum control input voltage is ± 10 *V*.
Maximum current permitted in the motor is 20 *A*.
Number of training sample is 500.
Number of training epoche is 150
Number of hidden layers is 2.

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