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Intelligent PI Controller for Speed Control of SEDM using MATLAB

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Abstract---Abstract-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 development of artificial Neural Network controller for D.C drives in the present the new ability of ANNs in estimating speed and controlling the separately excited D.C. motor, The neural control scheme consist of neural controller, which is used to generate a control signal for converter. ANN has different size of hidden layers according to different control strategies with "trainlm" training function [15].The aim of this proposed scheme tracking performance of separately excited D.C. motor and compare with the conventional (PI) control strategy [6]. Performance of these new controllers has been verified through simulation using MATLAB/SIMULINK package.

Index Terms— **DC motor, ANN, PI controller, NARMA-L2 control.**

I. INTRODUCTION

The introduction of variable-speed drives increases the automation and productivity and, in the process, efficiency. Nearly 65 % of the total electric energy produced in the USA is consumed by electric motors. Decreasing the energy input or increasing the efficiency of the mechanical transmission and processes can reduce the energy consumption. The system efficiency can be increased from 15 to 27% by the introduction of variable-speed drive operation in place of constant-speed operation. The energy-saving aspect of variable-speed drive operation has the benefits of conservation of valuable natural resources, reduction of atmospheric pollution through lower energy production and consumption, and competitiveness due to economy.

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. The control algorithms and analysis have been developed to facilitated dynamic simulation with personal computers.

II. PRINCIPLES OF DC MOTOR SPEED CONTROL

The principle of speed control for dc motors is developed from the basic emf equation of the motors. Torque, flux current, induced emf, and speed are normalized to present the motor characteristics. Two types of control arc available: armature control and field control. These methods arc combined to yield a wide range of speed control. The torque-speed characteristics of the motor are discussed for both directions of rotation and delivering both motoring and regenerating torques in any direction of rotation. Such an operation, known as four quadrant operation, has a unique set of requirements on the input voltage and current to the dc motor armature and field. These requirements are identified for specifying the power stage [8]. Modern power converters constitute the power stage for variable-speed dc drives. These power converters are chosen for a particular application depending on a number of factors such as cost, input power source, harmonics, power factor, noise, and speed of response Controlled-bridge rectifiers fed from single-phase and three-phase ac supply are considered in this chapter. The theory, operation and control of the three-phase controlled-bridge rectifier is considered in detail because of its wide-spared use. A model for the power Converter is derived for use in simulation and controller design. Two· and four quadrant dc motor drives and their control are developed.

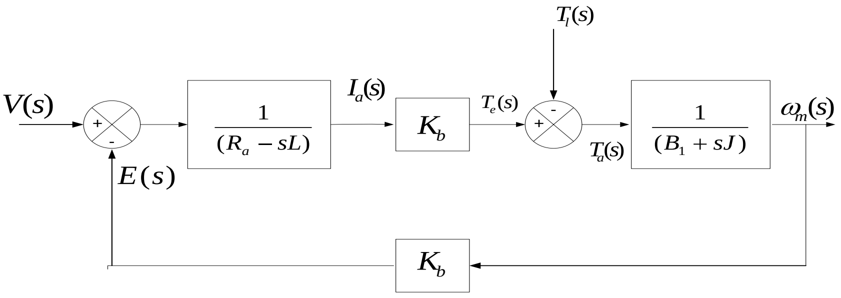


Fig 1 Block diagram of DC motor

A. Fundamental Relationship

The dependence of induced voltage on the field flux and speed has been derived above and is given as

$$e = K\phi_f\omega_m \qquad (1)$$

Where e = back e.m.f

K= motor constant

ϕ_f=field flux

ω_m=motor speed.

The field flux is proportional to the field current if the iron is not saturated and is represented as

$$\phi_f \propto i_f \qquad (2)$$

by substituting (2) in to equation (1) the speed is expressed as

$$\omega_m \propto \frac{e}{\phi_f} \propto \frac{e}{i_f} \propto \frac{(v - i_a R_a)}{i_f} \qquad (3)$$

Where *v* and i_a are the applied voltage and armature current, respectively. From equation (3), it is seen that the rotor speed is dependent on the applied voltage and field current. Since the resistive armature voltage drop is very small compared to the rated applied voltage, the armature current has only a secondary effect. To make its effect dominant an external resistor in series with armature can be controlled. In that case, the speed can be controlled, by varying step wise the value of the external resistor as a function of operational speed. Power dissipation in the external resistor leads to lower efficiency.

B. Field Control

In field control, the applied armature voltage v is maintained constant. Then the speed is represented by equation

$$\omega_m \propto \frac{1}{i_f} \qquad (4)$$

The rotor speed is inversely proportional to the field current, by varying the field current, the rotor speed is changed. Reversing the field current changes the rotational direction. By weakening the field flux, the speed can be increased. The upper speed is limited by the commutator segment. It is not possible to strengthen the field flux beyond its rated (nominal) value, on account of saturation of steel laminations. Hence, field control for speed variation i_a not suitable below the rated (nominal) speed.

C. Armature control

In this mode, the field current is maintained constant. Then the speed is derived from equation (5) as

$$\omega_m \propto (V - i_a R_a) \qquad (5)$$

Hence, varying the applied voltage changes the speed. Reversing the applied voltage changes the direction of rotation of the motor. Armature control has the advantage controlling the armature current swiftly, by adjusting the applied voltage. The response is determined by the armature time constant, which has a very low value. In contract the field time constant is at least 10 to 100 times greater than the armature time constant. The large time constant of the field causes the response of the field- controlled dc motor drive to be slow and sluggish. Armature control is limited in speed by the limited magnitude of the available dc supply voltage and armature winding insulation. If supply dc voltage is varied from zero to nominal value, than the speed can be controlled from zero to nominal value. Therefore, armature control is ideal for speed lower than rated speed, field control is suitable for greater than the rated speed.

III. DESIGN OF CONTROLLERS

The overall closed loop system is shown in Fig1 it is seen that the current loop does not contain the inner induced-emf loop. 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. That way the dynamics of the inner loop can be simplified and the impact of the outer loop on its performance could be minimized. The design of the current and speed controllers is considered in this section.

A. Current Controller

The current control loop is shown in Fig.3.4 the loop gain function is

$$GH_i(s) = \left\{\frac{K_1 K_c K_r H_c}{T_c}\right\} \cdot \frac{(1+sT_c)(1+sT_m)}{s(1+sT_1)(1+sT_2)(1+sT_r)} \qquad (6)$$

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: $(1+sT_m) \cong sT_m$ (7)

this reduces the loop gain function to

$$GH_i(s) = K \cdot \frac{(1+sT_c)}{(1+sT_1)(1+sT_2)(1+sT_r)} \qquad (8)$$

Where

$$K = \frac{K_1 K_c K_r H_c T_m}{T_c} \qquad (9)$$

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

$$T_r < T_2 < T_1 \qquad (10)$$

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

$$T_c = T_2 \qquad (11)$$

Then the loop function is

$$GH_i(s) = \frac{K}{(1+sT_1)(1+sT_r)} \qquad (12)$$

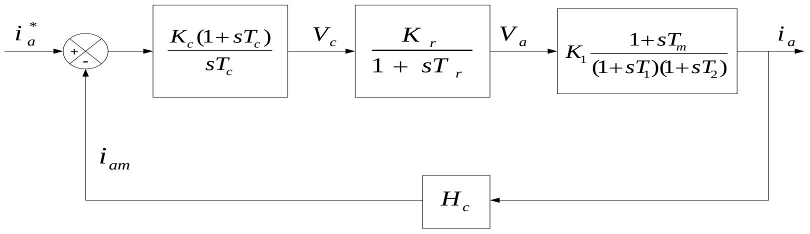


Fig 2 Current Control Loop

The characteristic equation or denominator of the transfer function between the armature current and its command is $(1+sT_1)(1+sT_r)+K$ (13)

this equation is expressed in standard form as

$$T_1 T_r \left\{ s^2 + s\left(\frac{T_1+T_2}{T_1 T_r}\right) + \frac{K+1}{T_1 T_r} \right\} \qquad (14)$$

From which the neural frequency and damping ratio are obtained as

$$\omega_n^2 = \frac{K+1}{T_1 T_r} \qquad (15)$$

$$\zeta = \frac{\frac{T_1+T_r}{T_1T_r}}{2\sqrt{\frac{K+1}{T_1T_r}}} \qquad (16)$$

Where ω_n and ζ 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

$$K+1 = \frac{\frac{\left(\frac{T_1+T_r}{T_1T_r}\right)^2}{2}}{\frac{1}{T_1T_r}} \qquad (17)$$

Realizing that

$$K>>1 \qquad (18)$$

$$T_1 \gg T_r \qquad (19)$$

Tells us that K is approximated as

$$K \cong \frac{T_1^2}{2T_1T_r} \cong \frac{T_1}{2T_r} \qquad (20)$$

by equating (3.76) to (3.87).the current-controller gain is evaluated

$$K_c = \frac{1}{2}.\frac{T_1T_c}{T_r}.\left(\frac{1}{K_1K_rH_cT_m}\right) \qquad (21)$$

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

$$GH_s(s) = \left\{\frac{K_sK_iK_bH_\omega}{B_tT_s}\right\}.\frac{(1+sT_s)}{s(1+sT_i)(1+sT_m)(1+sT_\omega)} \qquad (22)$$

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

$$(1+sT_m) = sT_m \qquad (23)$$

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

$$GH_s(s) \cong K_2.\frac{K_s}{T_s}\frac{(1+sT_s)}{s^2(1+sT_4)} \qquad (24)$$

Where

$$T_4 = T_i + T_\omega \qquad (25)$$

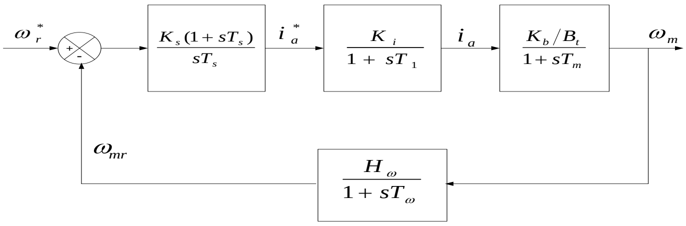


Fig 3.Representation of the Outer Speed Loop in the DC Motor Drive

$$\mathrm{K_2} = \frac{\mathrm{K_iK_bH_\omega}}{\mathrm{B_tT_m}} \qquad (26)$$

The closed loop transfer function of speed to its command is

$$\frac{\omega_m(s)}{\omega_r^*(s)} = \frac{1}{H_\omega}\left[\frac{\frac{K_2K_s}{T_s}(1+sT_s)}{s^3T_4+s^2K_2K_s+\frac{K_2K_2}{T_s}}\right] = \frac{1}{H_\omega}\frac{(a_0+a_1)}{(a_0+a_1s+a_2s^2+a_3s^3)} \qquad (27)$$

Where

$$a_0 = K_2K_s/T_s \qquad (28)$$

$$a_2 = K_2K_s \qquad (29)$$

$$a_2 = 1 \qquad (30)$$

$$a_3 = T_4 \tag{31}$$

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

$$\left|\frac{\omega_m(j\omega)}{\omega_r^*(j\omega)}\right| = \frac{1}{H_\omega}\sqrt{\frac{a_0^2+\omega^2 a_1^2}{\{a_0^2+\omega^2(a_1^2-2a_0a_2)+\omega^4(a_2^2-2a_1a_3+\omega^6a_3^2)+\omega^6a_3^2\}}} \tag{32}$$

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

$$a_1^2 = 2a_0\,a_2 \tag{33}$$

$$a_2^2 = 2a_1\,a_3 \tag{34}$$

Substituting these conditions in terms of the motor and controller parameters given in (35) into (38) yields

$$T_s^2 = \frac{2T_s}{K_sK_2} \tag{35}$$

Resulting in

$$T_sK_s = \frac{2}{K_2} \tag{36}$$

Similarly

$$\frac{T_{ss}^2}{K_s^2K_2^2} = \frac{2T_s^2T_4}{K_sK_2} \tag{37}$$

Thus after simplification, gives the speed – controller gain as

$$K_s = \frac{1}{2K_2T_4} \tag{38}$$

Substituting equation (38) into equation (36) gives the time constant of the speed controller as

$$T_s = 4T_4 \tag{39}$$

Substituting for K_s and T_s into (27) gives the closed-loop transfer function of the speed to its command as

$$\frac{\omega_m(s)}{\omega_m^*(s)} = \frac{1}{H_\omega}\left[\frac{1+4T_4s}{1+4T_4s+8T_4^2s^2+8T_4^3s^3}\right] \tag{40}$$

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$1/2T_4$. This clearly shows the influence of the subsystem parameters on the system dynamics. A clear understanding of this would help the proper selection of the subsystems to obtain the required dynamic performance or the speed-controlled motor-drive system. Further, this derivation demonstrates that the system behaviour to a large degree depends on the subsystem parameters rather than only on the current and speed-controller parameters or on the sophistication or their design [5]

IV. SIMULINK MODELAND RESULTS

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

In this control strategy, current control and speed control are applying for improving the performance of DC motor drive. In fig.5. Shows the simulation plant model for this case. The results are shown in fig.5.2 (a) and (b).The response shows that the speed of the motor can be achieved the steady state value with in a small time or the settling time of motor drive is reduced.

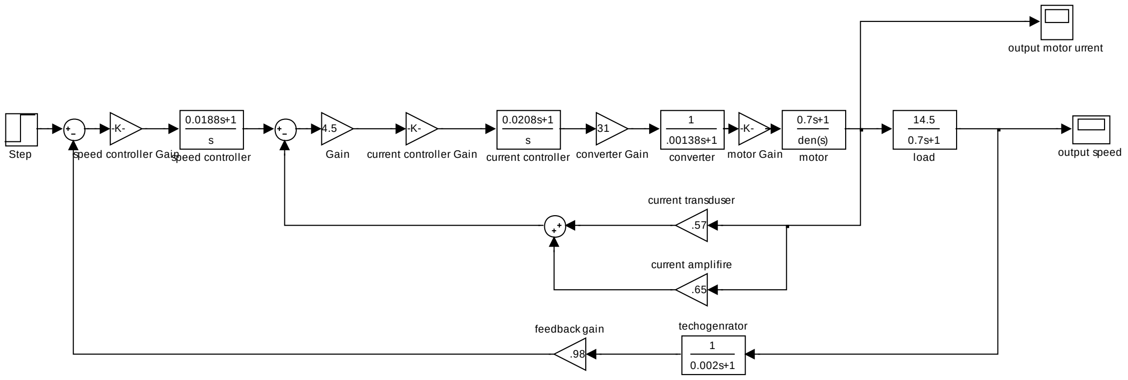


Fig 4 Simulink Plant Model with Speed and Current Controllers

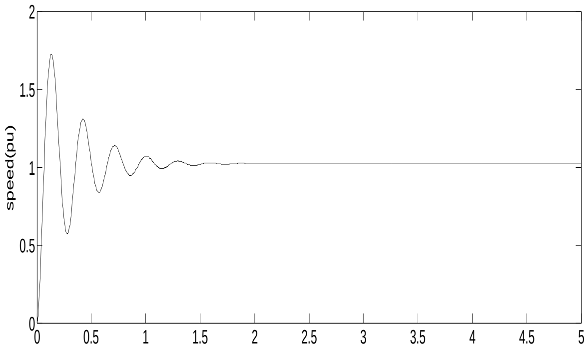


Fig 5 (a) Output motor speed response

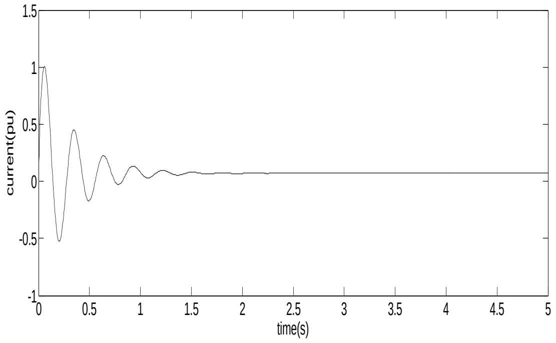


Fig 5 (b) Output motor current response

Table 1 Specification of Speed and Current Response

Specification	Speed response	Current response
Settling time t_s (sec.)	1.8	1.7
Maximum overshoot Mp(p.u.)	1.7	1.00
Steady state error (p.u.)	0.02	0.03

B. Control strategy with ANN

In this text consider the simulink modelling 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 are 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. In this case study use the ANN controller to generate the control signal for converter to control the speed of motor according to the plant output. For the generation of data use the reference plant, which has applied different control strategy, shown in different reference plant model. The plat 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:

I. Using only current controller
II. Using only speed controller

I. Response of system using only current control strategy with ANN

In this case reference plant have only current controller, shown in fig.7.The input and output data are generated by this reference plant which is shown in fig.9.The complete plant layout is given in fig.6.The neural network specification are shown in fig.8.The response of the system with simulink plant model with ANN, using current control strategy are shown in fig. 7.The ANN specification and results are shown in table 2 and 3.The result shows that the response of the system is better than using conventional PI controller.

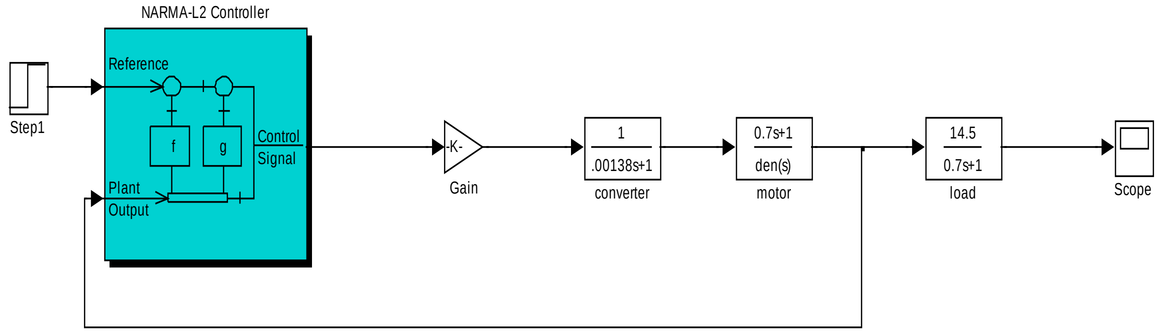


Fig 6 Simulink Plant Model Using Only Current Control Strategy with ANN

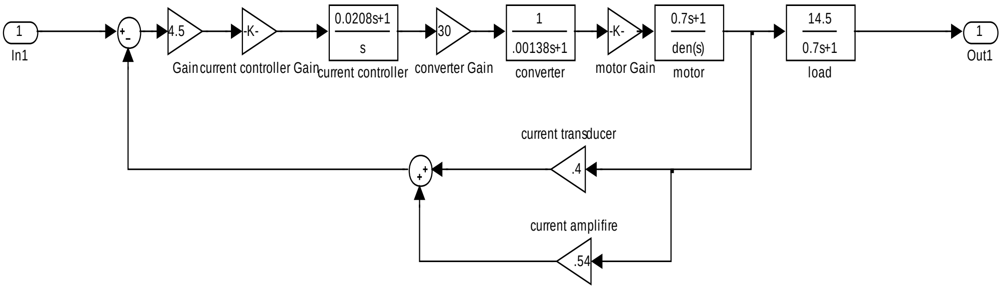
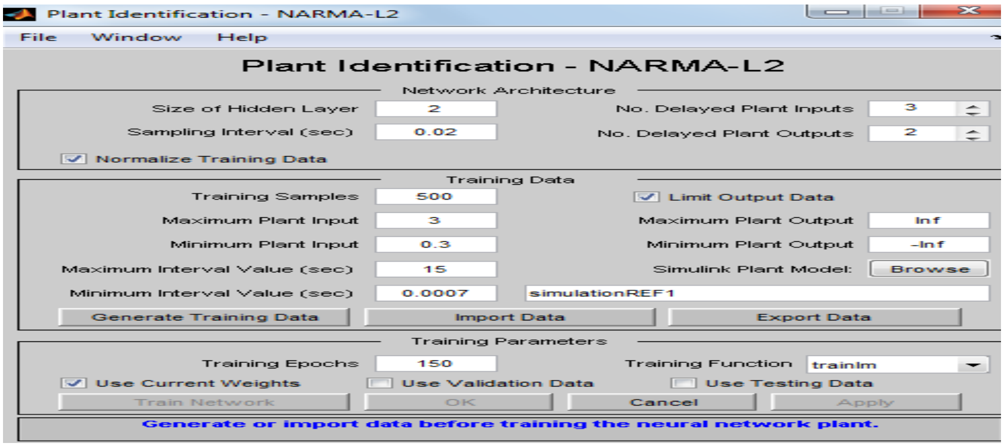


Fig 7 Simulink Reference Plant Model for Training of ANN with Current Controller



Plant Identification - NARMA-L2

Network Architecture

Size of Hidden Layer: 2
Sampling Interval (sec): 0.02
☑ Normalize Training Data
No. Delayed Plant Inputs: 3
No. Delayed Plant Outputs: 2

Training Data

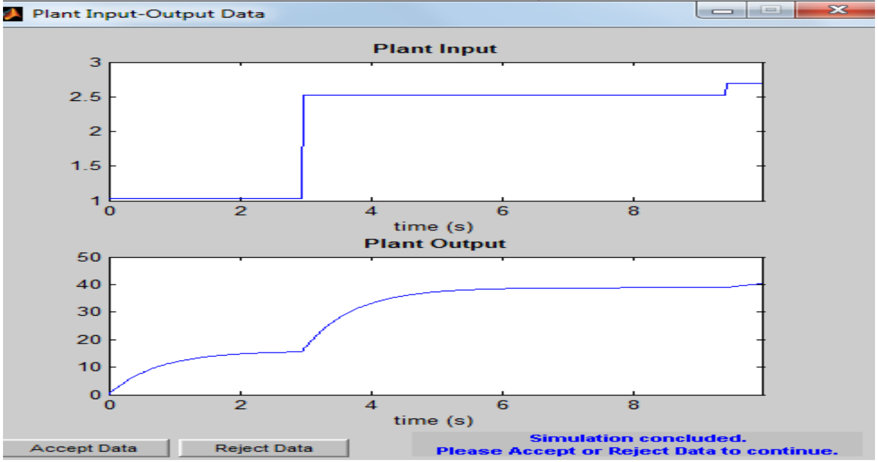
Training Samples: 500
Maximum Plant Input: 3
Minimum Plant Input: 0.3
Maximum Interval Value (sec): 15
Minimum Interval Value (sec): 0.0007
☑ Limit Output Data
Maximum Plant Output: Inf
Minimum Plant Output: -Inf
Simulink Plant Model: simulationREF1

Training Parameters

Training Epochs: 150
Training Function: trainlm
☑ Use Current Weights
☐ Use Validation Data
☐ Use Testing Data

Generate or import data before training the neural network plant.

Fig 8 ANN and Plant Specification Model with Only Current Control Strategy



Simulation concluded.
Please Accept or Reject Data to continue.

Fig 9 Plant Input and Output Generated By Reference Plant for ANN

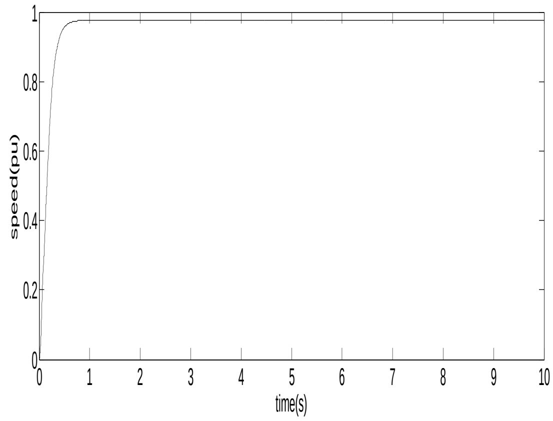


Fig 10 Plant Output With Current Control Strategy Using ANN as Current Controller

Table 2 Results of ANN as current controller

Results	
Settling Time t_s (sec.)	0.85
Stead state value (p,u.)	0.97
Steady state error (p.u.)	0.03

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

In this case plant layout is shown in fig.12. Only change the plant specification of ANN and reference plant model shown in fig.13. ANN controller speciation and results are given in table 4 & 5 respectively. The results show that the response of the system is not so poor but the settling time is more in comparison to (I).

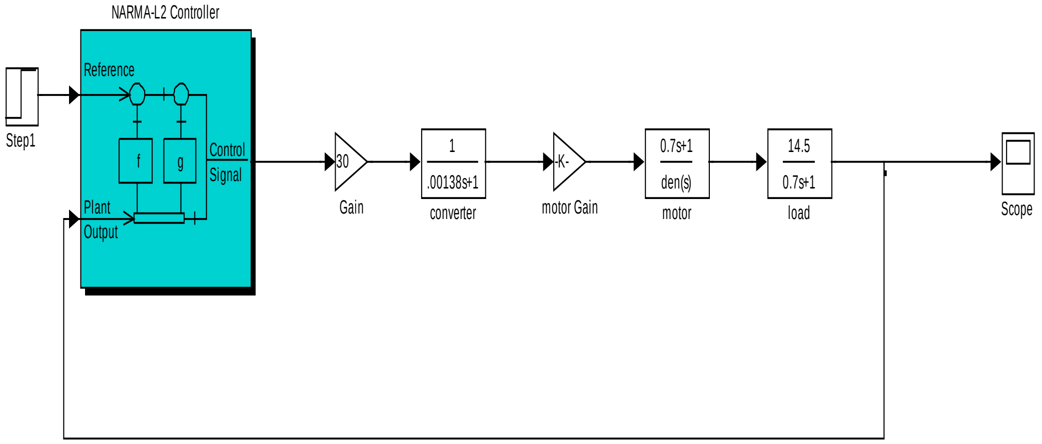


Fig 11 Simulink Plant Model Using Only Speed Control Strategy with ANN

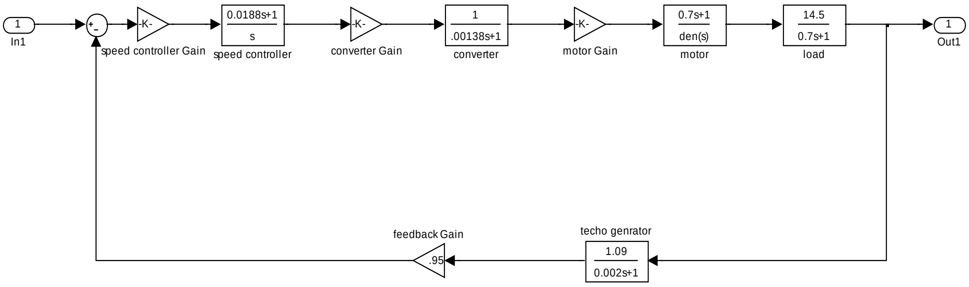
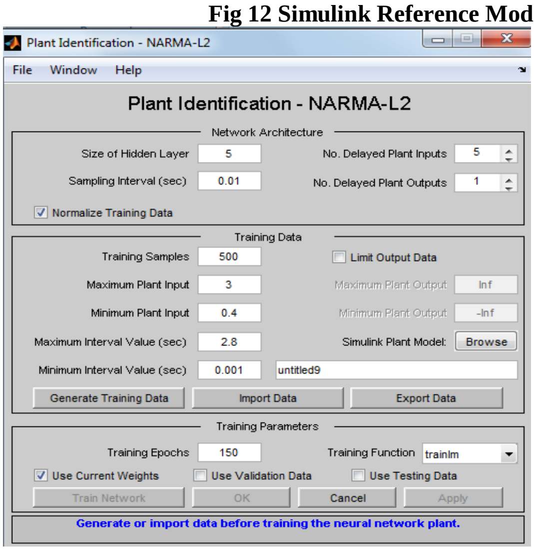


Fig 12 Simulink Reference Model for Training of ANN with Speed Controller



Plant Identification - NARMA-L2

Network Architecture

Size of Hidden Layer: 5
No. Delayed Plant Inputs: 5
Sampling Interval (sec): 0.01
No. Delayed Plant Outputs 1
☑ Normalize Training Data

Training Data

Training Samples: 500
☐ Limit Output Data
Maximum Plant Input: 3
Maximum Plant Output: Inf
Minimum Plant Input: 0.4
Minimum Plant Output: -Inf
Maximum Interval Value (sec): 2.8
Simulink Plant Model: Browse
Minimum Interval Value (sec): 0.001
untitled9

Training Parameters

Training Epochs: 150
Training Function: trainlm
☑ Use Current Weights
☐ Use Validation Data
☐ Use Testing Data

Generate or import data before training the neural network plant.

Fig 13 ANN and Plant Specification Model with Only Speed Control Strategy

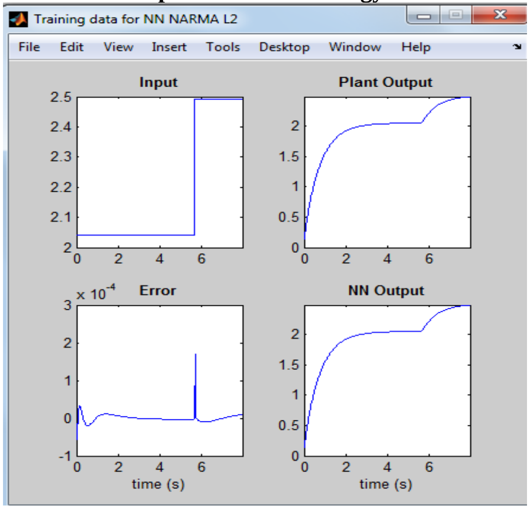


Fig 14 .Plant Input and Output Generated by Reference Plant for ANN

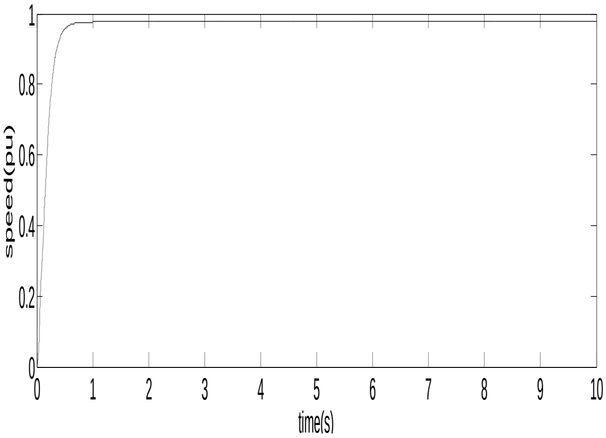


Fig 15 Plant Output Speed Control Strategy Using ANN as Speed Controller

Table 3 ANN Plant Results as speed controller

Results	
Settling Time t_s (sec)	0.97
Stead state value (p,u.)	0.96
Steady state error (p.u.)	0.04

V. RESULTS DISCUSSION

In different case study either takes the conventional PI controller or modern control approach using neural networks, the performance of dc motor drive is more better in case of modern control approach. 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.

VI. CONCLUSION

A DC Motor using ANN controller is modelled and simulation of the complete drive system is carried out using the matlab/simulink package. The controller has been trained for different reference plant with using different type of control strategy. The D.C motor has been successfully controlled using an ANN. By using ANN don't have to calculate the parameters of the motor when designing the system control. The results prove that the complete D.C. drive system is robust to parameter variations. The dynamic and steady state performance of the ANN based controlled drive is much better than the PI controlled drives, which is shown by table 2 and 3. Excellent results added to the simplicity of the drive system, makes the ANN based control strategy suitable for a vast number of industrial, paper mills etc. The appreciable advantage of control system using ANN above the conventional one, when parameters of the DC motor is variable during the operation of the motor. The satisfied ability of the system control with ANN is much better than conventional control system.

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