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Speed Control of Separately Excited DC Motor

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Abstract: This paper proposes the speed control of a separately excited dc motor varying armature voltage. The novelty of this paper lies in the application of nonlinear autoregressive-moving average L2 controller for the speed control of SEDM. This paper also discusses speed control of a SEDM using chopper circuit. The performance of the proposed system has been compared with the traditional one using conventional controllers. The entire system has been modeled using MATLAB 7.0 toolbox. It has been found that both PI and hysteresis current controllers could be eliminated by the use of NARMA-L2 controller.

Keywords: Chopper Circuit, NARMA-L2, SEDM, Speed control

INTRODUCTION

Direct current (DC) motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, and robotic manipulators due to precise, wide, simple, and continuous control characteristics. Traditionally rheostatic armature control method was widely used for the speed control of low power dc motors. However the controllability, cheapness, higher efficiency, and higher current carrying capabilities of static power converters brought a major change in the performance of electrical drives. The desired torque-speed characteristics could be achieved by the use of conventional proportional-integral-derivative (PID) controllers. As PID controllers require exact mathematical modeling, the performance of the system is questionable if there is parameter variation. In recent years neural network controllers (NNC) were effectively introduced to improve the performance of nonlinear systems. The application of NNC is very promising in system identification and control due to learning ability, massive parallelism, fast adaptation, inherent approximation capability, and high degree of tolerance.

A constant-power field weakening controller based on load-adaptive multi-input multi-output linearization technique has been proposed to effectively operate a separately excited dc motor in the high-speed regimes[1]. A single-phase uniform PWM ac-dc buck-boost converter with only one switching device able to produce a controllable dc voltage ranging from zero to more than the maximum value of input ac voltage has been used for armature voltage control method of a separately excited dc motor[2]. In[3] a general simulation method based on an estimation of the average value of voltages and currents on each PWM period, to improve the simulation speed has been proposed, analyzed and tested for an efficient computation of the torque-speed characteristics of the drives using poly-phase brushless DC motors fed by a PWM inverter with current regulation. An open loop control system which can predict the dynamic behavior of systems involving mechanic and electronic modules has been successfully designed and implemented to control the speed of a DC motor[4]. Several other speed control techniques using conventional controllers have been reported in[5,17]. Recently, the superior performance of artificial intelligence (AI) based controllers urged power system and power electronic engineers to replace conventional speed control circuit with intelligent speed controllers[18]-[30].

In this paper, NARMA-L2 controller has been proposed for the speed control of separately excited dc motor in the constant torque region. The novelty of this paper lies in the application of NARMA–L2 controller for the speed control of separately excited dc motor. This paper also discusses speed control of a SEDM using chopper circuit. The speed control techniques of SEDM are detailed in the second part of this paper. Simulation results in the third part demonstrate the successful application of NARMA-L2 controller to control the speed of a separately excited dc motor.

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Speed control techniques of separately excited dc motor: The speed of a separately excited dc motor could be varied from zero to rated speed mainly by varying armature voltage in the constant torque region. Whereas in the constant power region, field flux should be reduced to achieve speed above the rated speed. The motor drives a mechanical load characterized by inertia J, friction coefficient D_m, and load torque TL. The specifications of the dc motor are detailed as follows:

Shaft power	–	5 hp
Rated voltage	–	240 V
Armature resistance	–	0.6 Ω
Armature inductance	–	0.012 H
Field resistance	–	240 Ω
Field inductance	–	120 H
Total inertia (J)	–	1 kgm^2
Viscous friction coefficient (B)	–	0.02 Nms
Coulomb friction torque (Tf)	–	0 Nm

a) Modeling and control of SEDM using MATLAB/SimPowerSystems: Fig. 1 shows the speed control circuit of an armature controlled separately excited dc motor using chopper circuit, and in Fig. 2 its MATLLAB/SimPowerSystems model[31] is shown. It consists of a separately excited dc motor fed by a DC source through a chopper circuit. A single GTO thyristor with its control circuit and a free-wheeling diode form the chopper circuit. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque TL. The control circuit consists of a speed control loop and a current control loop. A proportional-integral (PI) controlled speed control loop senses the actual speed of the motor and compares it with the reference speed to determine the reference armature current required by the motor. One may note that any variation in the actual speed is a measure of the armature current required by the motor. The current control loop consists of a hysteresis current controller (HCC). The block diagram of a hysteresis current controller is shown in Fig. 3. HCC is used to generate switching patterns required for the chopper circuit by comparing the actual current being drawn by the motor with the reference current. A positive pulse is generated if the actual current is less than reference armature current, whereas a negative pulse is produced if the actual current exceeds reference current.

Hysteresis current control is a method of controlling a power electronic converter so that an output current is generated which follows a reference current waveform. A hysteresis current controller is implemented with a closed loop control. The difference between the desired current, and the current being injected is used to control the switching of the chopper circuit. When the error reaches an upper limit namely upper hysteresis limit, GTO is switched to force the current the current down. On the other hand when the error reaches the lower hysteresis limit, a positive pulse is produced to increase the current. The minimum and maximum values of the error signal are e_{min} and e_{max}. The range of the error signal, e_{max}-e_{min}, directly controls the amount of ripple in the output current and is called the hysteresis band. Thus the armature current is forced to stay within the hysteresis band determined by the upper and lower hysteresis limits.

b) Modeling and control of SEDM using Simulink model: The speed control circuit of a SEDM using Simulink is shown in Fig. 4, where

V_t	–	Supply voltage (V)
E_b	–	Back emf (V)
R_a	–	Armature resistance (Ω)
L_a	–	Armature inductance (H)
R_f	–	Field resistance (Ω)
L_f	–	Field inductance (H)
I_f	–	Field current (A)
I_a	–	Armature current (A)
w_m	–	Speed (rad/s)
J	–	Rotor inertia of motot (kgm^2)
D_m	–	Viscous friction of motor (Nms)

In Fig.4, the GTO is modeled using a switch. The switch block has three inputs: the middle input controls which of the two other inputs is routed to the output. If the control input is one, 240 V is routed to the output, on the other hand if the control input is zero, a zero will be routed to the output.

c) The Speed control of SEDM using NARMA-L2 controller:

NARMA-L2 Controller: The learning ability, self-adapting, and super-fast computing features of ANN make it well suited for the control of electrical power systems in many applications such as: electric load forecasting, transient ability assessment, active power filter, dynamic voltage restorer, and unified power quality conditioner. In learning process, neural network adjusts its structure such that it will be able to to follow the supervisor. The learning is repeated until the difference between network output and the supervisor is low.

(i) System Identification Stage: NARMA-L2 controller, a multilayer neural network

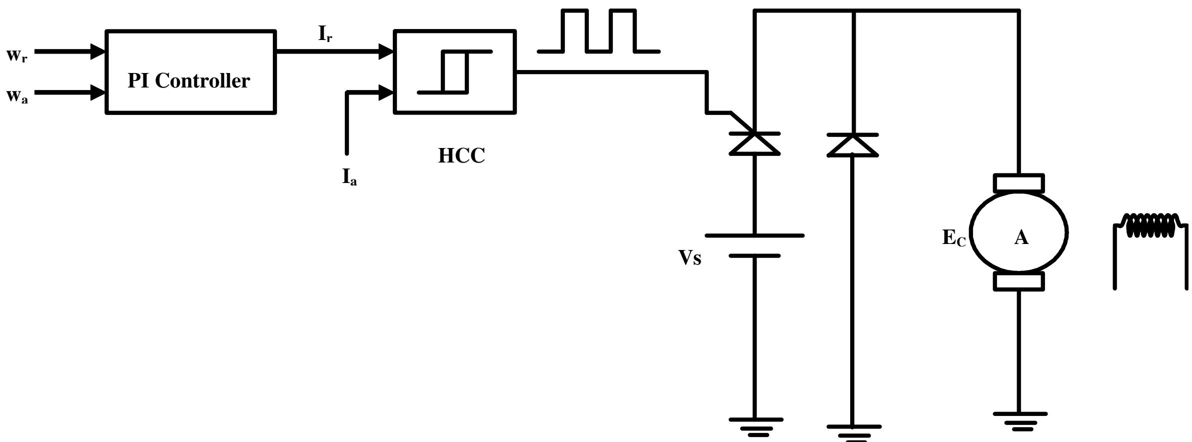


Fig. 1: Speed control circuit of a separately excited dc motor

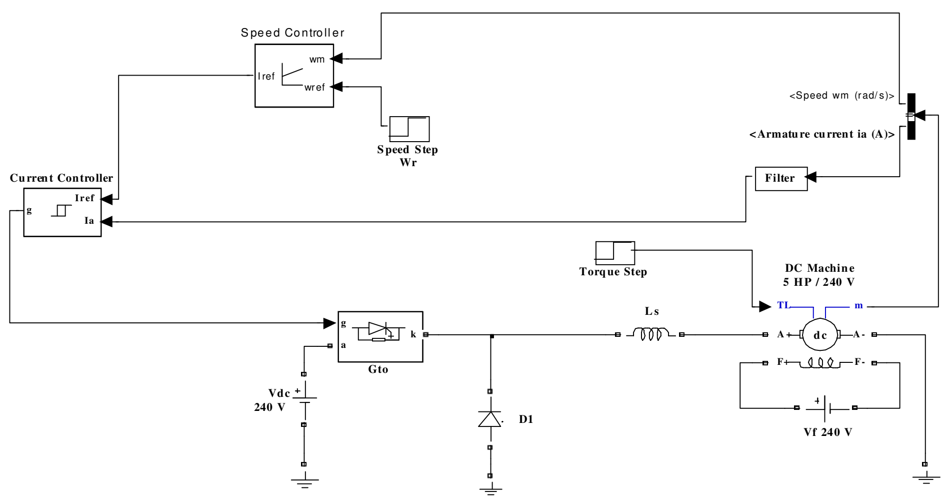


Fig. 2: MATLAB/SimPowerSystems model of a separately excited dc motor speed control

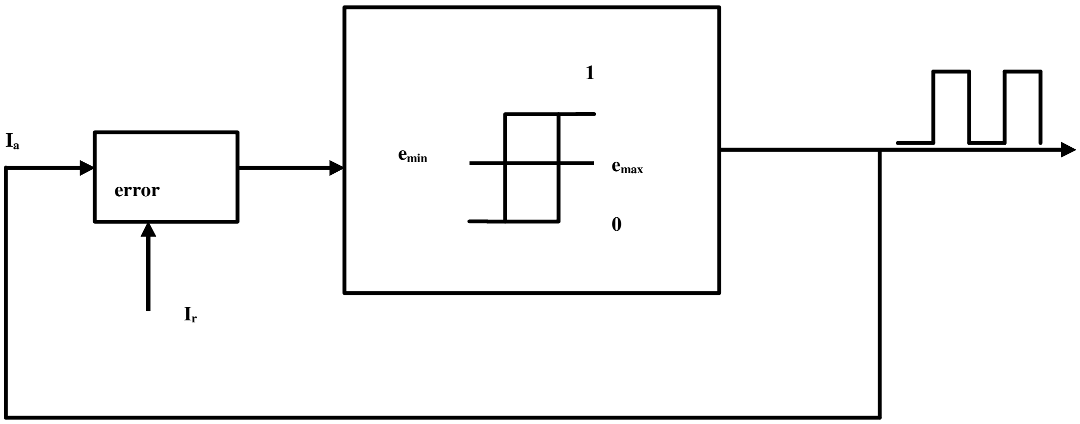


Fig. 3: Block Diagram of a Hysteresis current controller

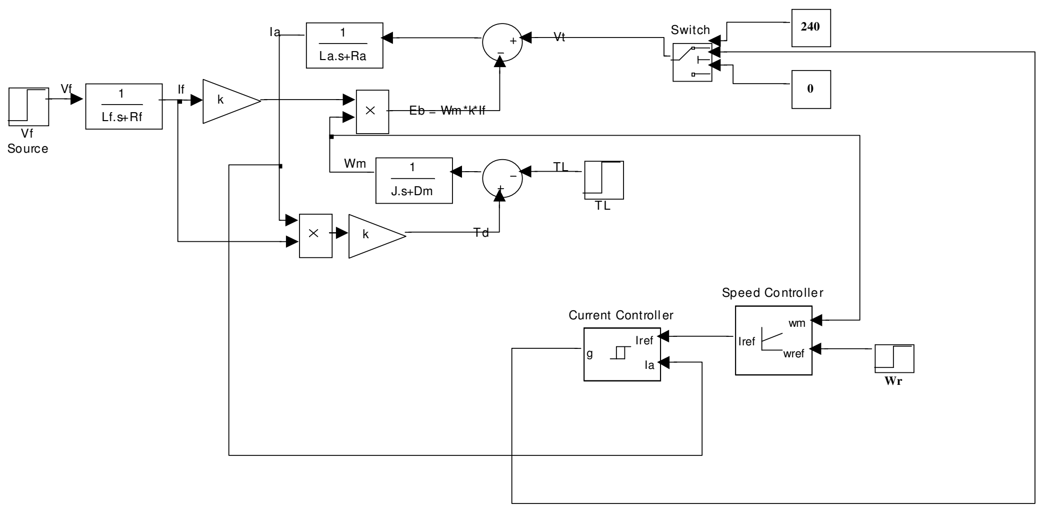


Fig. 4: Speed Control Circuit of SEDM using Simulink

has been successfully applied in the identification and control of dynamic systems[32]. System identification and control design are the two steps involved in using NARMA-L2 controller. In the system identification stage a neural network model of the plant to be controlled is developed. Fig. 5 shows the block diagram representation of the system identification stage. In the control design stage, the neural network plant model is used to train the controller.

In the system identification stage a neural network plant model must be developed before the controller is used. The plant model predicts future plant outputs. The plant model has only one hidden layer. The specifications of the plant model are tabulated in Table 1.

Table 1: Plant model specifications

Size of hidden layer	9
Sampling interval (s)	6.254e-5
No. of delayed plant inputs	3
No. of delayed plant outputs	2
Training samples	40000
Maximum plant input	240
Minimum plant input	0
Maximum interval value (s)	1
Minimum interval value (s)	0.5
Maximum plant output	120
Minimum plant output	0
Training Epochs	100
Training Function	trainlm
Use current weights	selected
Use validation data	unselected
Use testing data	unselected

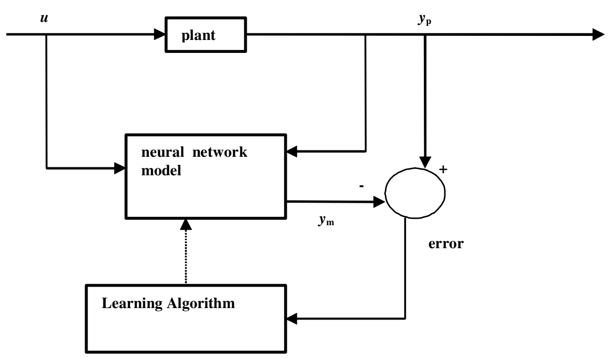


Fig. 5: Block diagram of system identification stage

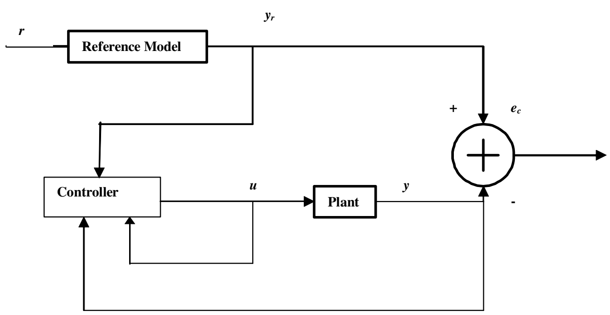


Fig. 6: NARMA-L2 controller

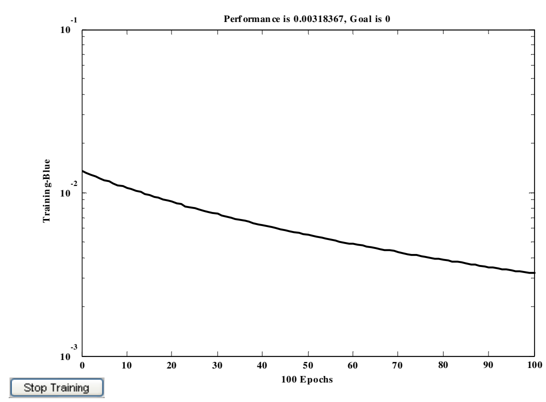


Fig. 7: Sample performance graph of a NARMA-L2 controller

(ii) Controller design stage: The central idea of this type of control is to transform nonlinear system dynamics by canceling the nonlinearities. Fig. 6 shows the block diagram representation of NARMA-L2 controller. Sample performance graph and training data obtained from a NARMA-L2 controller are illustrated in Fig. 7 and Fig. 8 respectively.

(iii) Simulink model of NARMA-L2 controlled Separately Excited DC Motor: The simulink model of a NARMA-L2 controlled separately excited dc motor is shown in Fig. 9. A simulink based plant model using PI controller is used to generate the required training data. The inputs of the controller are the reference speed and the actual speed and the output is the driving voltage to the motor.

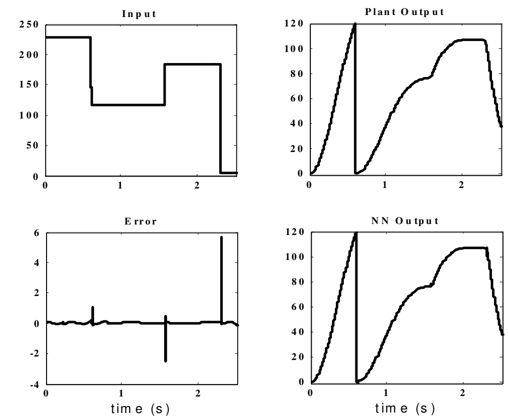


Fig. 8: Training Data of a NARMA-L2 controller

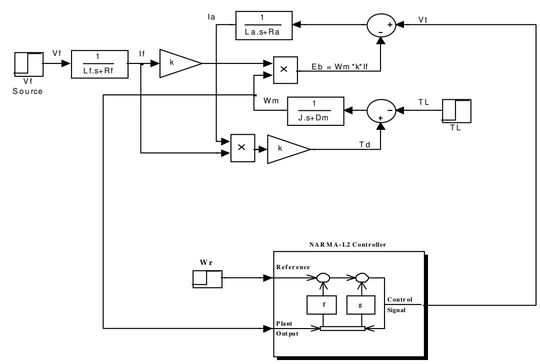


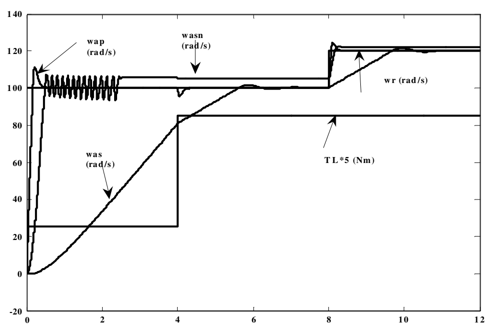
Fig. 9 Simulink model of NARMA-L2 controlled Separately excited DC Motor

RESULTS AND DISCUSSION

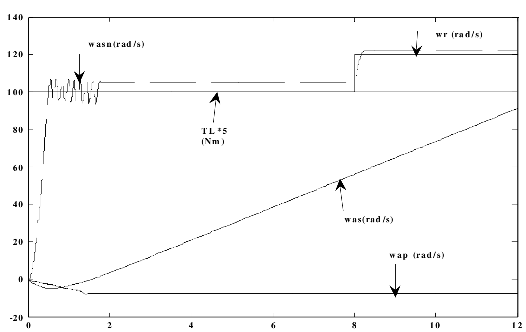
NARMA-L2 controller has been successfully modeled and tested to control the speed of a separately excited dc motor. MATLAB 7.0 toolbox is used to model the system. The performance of the developed system is compared with two other systems; one with SimPowerSystems based chopper controlled dc motor model and the other one using simulink model. In chopper controlled circuits, a PI controller is used to generate the reference current and HCC is used to generate the switching patterns required by the chopper circuit. It has been found that the chopper and its control circuit could be eliminated by the use of NARMA-L2 controller. The validity of the system has been examined with different load torque, and different speeds. Simulation results are plotted as shown in Fig. 10. Plots of rated speed (wr), load torque (TL), actual speed of the motor using SimPowerSystems model (wap), simulink model (was) and that of using NARMA-L2 controller (wasn) are shown in Fig. 10. Comparison of Figures 10.a, 10.b, and 10.c shows that NARMA-L2 controller is able to regulate the speed well above the rated conditions on the assumption that 50 % overload capacity is allotted.

CONCLUSION

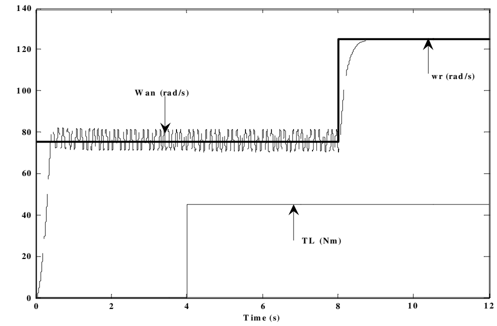
Speed controller system based on NARMA-L2 controller has been successfully developed using MATLAB to control the speed of a separately excited dc motor. The novelty of this paper lies in the application of NARMA–L2 controller to control of a separately excited dc motor. This paper also discusses modeling and control of SEDM using SimPowerSystems and simulink models. The performance of the system has been compared using different types of controllers. It has been found that NARMA-L2 controller is able to regulate the speed well above the rated values.



a. wr = 100 rad/s & 120 rad/s; TL = 5 Nm & 17 Nm



b. wr = 100 rad/s & 120 rad/s; TL = 20 Nm



c. wr = 75 rad/s &120 rad/s; TL = 0 Nm & 1.5 × TL rated (Nm)

Fig. 10: Response of the system using different controllers

REFERENCES

1. Zuo Z. Liu, Fang L. Luo, and Muhammad H. Rasid, “High performance nonlinear MIMO field weakening controller of a separately excited dc motor,” Electric Power Systems Research, vol. 55, issue 3, Sep. 2000, pp. 157-164.
2. Nabil A. Ahmed, “Modeling and simulation of ac-dc buck-boost converter fed dc motor with uniform PWM technique,” Electric Power Systems Research, vol.73, issue 3, Mar. 2005, pp. 363-372.
3. J. Figueroa, C. Brocart, J. Cros, and P. Viarouge, “Simplified simulation methods for polyphase brushless DC motors,” Mathematics and Computers in Simulation, vol. 63, issues 3-5, Nov. 2003, pp. 209-224.
4. J. Santana, J. L. Naredo, F. Sandoval, I. Grout, and O. J. Argueta, “Simulation and construction of a speed control for a DC series motor,” Mechatronics, vol. 12, issues 9-10, Nov.-Dec. 2002, pp. 1145-1156.
5. Charles I. Ume, John Ward, and Jay Amos, “Application of MC68HC11 microcontroller for speed control of a DC motor,” Journal of Microcomputer Applications, vol. 15, issue 4, Oct. 1992, pp. 375-385.
6. R. M. Stephan, V. Hahn, J. Dastych, and H. Unbehauen, “Adaptive and robust cascade schemes for thyristor driven DC-motor speed control,” Automatica, vol. 27, issue 3, May 1991, pp. 449-461.
7. Sofyan A. Abdelhay and M. Azharul-haque, “DC-motor control using a minimum-variance self-tuner,” Microprocessing and Microprogramming, vol. 19, issue 3, Jun. 1987, pp. 227-231.
8. MK Refai, “Microprocessor-based digital controller for DC motor speed control,” Microprocessor and Microsystems, vol. 10, issue 10, Dec. 1986, pp. 543-552.

9. M. Pachter, "Speed control of a field controlled D.C. traction motor," Automatica, vol. 17, issue 4, Jul. 1981, pp. 627-630.
10. S. P. Chowdhury, S. K. Basu, and R. Mondal, "A laboratory model of microcomputer based speed control of a DC motor with interactive display," IEEE Tran. Power Systems, vol. 7, issue 1, Feb. 1992, pp. 403-409.
11. F. I. Ahmed, A. M. El-Tobshy, A. A. Mahfouz, and M. M. Ibrahim, "(I-P) adaptive controller for DC motor drives: a hardware and software approach," in Conf. Publ. No. 455, UKACC Int. Conf. Control, 1-4 Sep. 1998, vol. 2, no.455, pp. 1146-1150.
12. Y. S. E. Ali, S.B. M. Noor, S. M. Bashi, and M. K. Hassan, "Microcontroller performance for DC motor speed control system," in national proc. Power Engineering Conf. 2003, pp. 104-109.
13. A. A. El-Samahy, "Speed control of DC motor using adaptive variable structure control," in Proc. 2000 IEEE 31st Annual Power Electronics Specialists Conf., vol. 3, 18-23 Jun. 2000, pp.1118-1123.
14. F. I. Ahmed, A. M. El-Tobshy, A. A. Mahfouz, and M. M. S. Ibrahim, "P-I and I-P controllers in a closed loop for DC motor drives," in Proc. Power Conversion Conf.-Nagaoka 1997, vol. 2, pp. 613-618.
15. S. E. Gaber and H. A. Yousef, "Efficiency optimized speed control of DC motors based on self tuning regulator," in Proc. ISIE 1993 IEEE Int. Symposium on Ind. Electronics, pp. 385-390.
16. A. S. Awad, E. A. Mohamed, M. M. Negm, and A. I. Said, "Speed control of DC motor drives based on efficient utilization of energy and optimal performance," in 14th IEE Intl. Conf. on Electricity Distribution.Part 1. Contributions, publ. no. 438, vol. 5, 2-5 Jun. 1997, pp. 22/1-22/5.
17. P. Chevrel, L. Sicot, and S. Siala, "Switched LQ controllers for DC motor speed and current control: a comparison with cascade control," 27th Annual IEEE Power Electronics Specialists Conf. 1996, vol. 1, 23-27 Jun. 1996, pp. 906-912.
18. M. D. Minkova, D. Minkov, J. L. Rodgerson, and R. G. Harley, "Adaptive neural speed controller of a dc motor," Electric Power Systems Research, vol. 47, issue 2, 15 Oct. 1998, pp. 123-132.
19. Ahmed Hussein, Kotaro Hirasawa, and Jinglu Hu, "A robust control method for a PV-supplied DC motor using universal learning networks," Solar Energy, vol. 76, issue 6, 2004, pp. 771-780.
20. D. Kukolj, F. Kulic, and E. Levi, "Design of the speed controller for sensorless electric drives based on AI techniques: a comparative study," Artificial Intelligence in Eng., vol. 14, issue 2, Apr. 2000, pp. 165-174.
21. Jui-Hong Horng, "Neural adaptive tracking control of a DC motor," Information Sciences, 1-4 Sept. 1999, vol. 118, issues 1-4, pp. 1-13.
22. Jawad Faiz, M. R. Azizian, and M. Aboulghasemian-Azami, "Simulation and analysis of brushless DC motor drives using hysteresis, ramp comparison and predictive current control techniques," Simulation Practice and theory, vol.3, issue 6, Jan. 1996, pp. 347-363.
23. G. A. Rovithakis and M. A. Christodoulou, "Direct adaptive regulation using dynamic neural networks: Application to dc motors speed control," Mathematics and Computers in Simulation, vol. 41, issues 1-2, Jun. 1996, pp. 53-62.
24. Luiz Eduardo Borges da Silva, Germano Lambert Torres, Ernesto Castillo Saturno, Alexandre P. Alves da Silva, and Xuan Dai Do, "Simulation of a neural net controller for motor drives," Mathematics and Computers in Simulation, vol. 38, issues 4-6, Aug. 1995, pp. 311-322.
25. E. G. Janardan, F. Gajendran, and P. M. S. Nambisan, "State feedback using artificial neural network for speed control of DC motor," in Proc. of the 1996 Int. Conf. Power Electronics, Drives, and Energy Systems for Ind. Growth," 8-11 Jan. 1996, vol. 2, pp. 753-756.
26. C. Machbub, A. S. Prihatmanto, and Y. D. Cahaya, "Design and implementation of adaptive neural networks algorithm for DC motor speed control system using simple microcontroller," Proc. of 2001 4th IEEE Intl. Conf. Power Electronics and Drive Systems, vol. 2, 22-25 Oct. 2001, pp. 479-483.
27. D. H. Rao and H. V. Kamat, "A neuro-PID speed controller for DC drives," Proc. 1996 Int. Conf. Power Electronics, Drives and Energy Systems for Ind. Growth," vol. 2, 8-11 Jan. 1996, pp. 757-763.
28. M. Minkova, D. Minkov, J. L. Rodgerson, and R. G. Harley, " Current limitation in the adaptive neural speed control of a DC motor," 4th IEEE AFRICON 1996, vol. 2, 24-27 Sept. 1996, pp. 837-842.
29. N. Barakat and R. Rajagopalan, "Speed control of a DC motor using a feedforward computed torque control scheme," in Proc. 1996 Int. Sym. on Intelligent control, 15-18 Sept. 1996, pp. 432-437.
30. A. M. N. Lima, J. H. F. Cavalcanti, and G. S. Deep, "On-line training of adaptive neural network controllers", 20th Int. Conf. Ind. Electronics, Control and Instrumentation, vol. 2, 5-9 Sep. 1994, pp. 1392-1395.
31. The Mathworks Inc., MATLAB/SimPowerSystems Demos/ Chopper-fed DC Motor Drive.
32. The Mathworks Inc., "Neural network tool box Version 4," pp. 6.1-6.40.