A Comparative Study of P-I, I-P, Fuzzy and Neuro-Fuzzy Controllers for Speed Control of DC Motor Drive

S.R. Khuntia, K.B. Mohanty, S. Panda, C. Ardil

Abstract—This paper presents a comparative study of various controllers for the speed control of DC motor. The most commonly used controller for the speed control of dc motor is Proportional-Integral (P-I) controller. However, the P-I controller has some disadvantages such as: the high starting overshoot, sensitivity to controller gains and sluggish response due to sudden disturbance. So, the relatively new Integral-Proportional (I-P) controller is proposed to overcome the disadvantages of the P-I controller. Further, two Fuzzy logic based controllers namely; Fuzzy control and Neuro-fuzzy control are proposed and the performance these controllers are compared with both P-I and I-P controllers. Simulation results are presented and analyzed for all the controllers. It is observed that fuzzy logic based controllers give better responses than the traditional P-I as well as I-P controller for the speed control of dc motor drives.

Keywords—Proportional-Integral (P-I) controller, Integral-Proportional (I-P) controller, Fuzzy logic control, Neuro-fuzzy control, Speed control, DC Motor drive.

I. INTRODUCTION

DIRECT Current motor drives have been widely used where accurate speed control is required. In spite of the fact that ac motors are rugged, cheaper and lighter, dc motor controlled by a thyristor converter is still a very popular choice in particular applications. The Proportional-Integral (P-I) controller is one of the conventional controllers and it has been widely used for the speed control of dc motor drives. The major features of the P-I controller are its ability to maintain a zero steady-state error to a step change in reference. At the same time P-I controller has some disadvantages namely; the undesirable speed overshoot, the sluggish response due to sudden change in load torque and the sensitivity to controller gains K_I and K_p.

In recent years, new artificial intelligence-based approaches

S. R. Khuntia is with the Electrical & Electronics Engineering Dept. at National Institute of Science & Technology, Berhampur, Orissa (e-mail: swastigunu@gmail.com).

K.B. Mohanty is working as an Assistant Professor in the Department of Electrical Engineering, National Institute of Technology, Rurkela 769008, India (e-mail: kbm@nitrkl.ac.in)

S. Panda is working as a Professor in the Department of Electrical and Electronics Engineering, NIST, Berhampur, Orissa, India, Pin: 761008. (e-mail: panda_sidhartha@rediffmail.com).

C. Ardil is with National Academy of Aviation, AZ1045, Baku, Azerbaijan, Bina, 25th km, NAA (e-mail: cemalardil@gmail.com)

have been proposed for the speed control of dc motors. Recently, fuzzy logic employing the logic of approximate reasoning continues to grow in importance, as it provides an inexpensive solution for controlling ill-known complex systems. Fuzzy controller has already been applied to phase controlled converter dc drive, linear servo drive, and induction motor drive.

II. CONTROLLER STRUCTURES

A. Proportional Integral (P-I) Controller

The block diagram of the drive with the P-I controller has one outer speed loop and one inner current loop, as shown in Fig. 1. The speed error E_N between the reference speed N_R and the actual speed N of the motor is fed to the P-I controller, and the K_p and K_i are the proportional end integral gains of the P-I controller. The output of the P-I controller E_1 acts as a current reference command to the motor, C_1 is a simple proportional gain in the current loop and K_{CH} is the gain of the GTO thyristor chopper, which is used as the power converter.
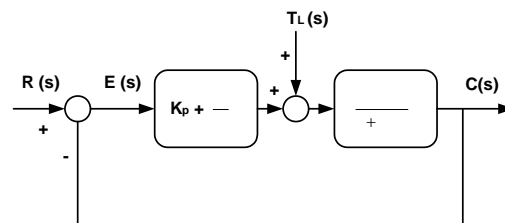

Fig. 1 P-I Controller Structure

The P-I controller has the form

$$\frac{E_1(s)}{E_N(s)} = \frac{K_p s + K_i}{s} \tag{1}$$

This is a phase-lag type of controller with the pole at the origin and makes the steady-state error in speed zero. The transfer function between the output speed N and the reference speed N_R is given by

$$\frac{N(s)}{N_R(s)} = \frac{AK_1 + AK_p s}{K_1 s^2 + K_2 s + K_3} \tag{2}$$

Where,

$A = C_1 K_{CH} K$

$K_1 = R_A B T_M + C_1 K_{CH} B T_M$

$K_2 = R_A B + K^2 + C_1 K_{CH} B + A K_P$

$K_3 = A K_1$

$T_M = J / B$

K_1 and K_P are controller gains, and R_A, B, T_M, etc. are motor and feedback constants (these are given in the Appendix).

The above equation introduces a zero, and therefore a higher overshoot is expected for a step change in speed reference.

B. Integral Proportional (I-P) Controller

The block diagram of the I-P controller has the proportional term K_P moved to the speed feedback path. There are three loops, one inner current loop, one speed feedback loop and one more feedback loop through the proportional gain K_P. The speed error E_N is fed to a pure integrator with gain K_1 and the speed is feedback through a pure proportional gain K_P.
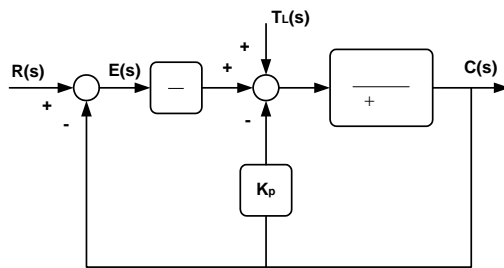

Fig. 2 I-P Controller Structure

The transfer function between the output speed N and the reference speed N_R is given by

$$\frac{N(s)}{N_R(s)} = \frac{A K_1}{K_1 s^2 + K_2 s + K_3} \tag{3}$$

When we compare the characteristic equations for both P-I and I-P controllers, the zero introduced by the P-I controller absent in the case of I-P controller, and thus the overshoot with an I-P controller is expected to be very small.

C. Fuzzy Controller

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. Fuzzy logic control doesn't need any difficult mathematical calculation like the others control system. While the others control system use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge. Although it doesn't need any difficult mathematical calculation, but it can give good performance in a control system. Thus, it can be one of the best available answers today for a broad class of challenging controls problems. A fuzzy logic control usually consists of the following:

Fuzzification: This process converts or transforms the measured inputs called crisp values, into the fuzzy linguistic values used by the fuzzy reasoning mechanism.

Knowledge Base: A collection of the expert control rules (knowledge) needed to achieve the control goal.

Fuzzy Reasoning Mechanism: This process will perform fuzzy logic operations and result the control action according to the fuzzy inputs.

Defuzzification unit: This process converts the result of fuzzy reasoning mechanism into the required crisp value.

The most important things in fuzzy logic control system designs are the process design of membership functions for inputs, outputs and the process design of fuzzy if-then rule knowledge base. They are very important in fuzzy logic control. The basic structure of Fuzzy Logic Controller is given in Fig. 3. For the DC drive, speed error (E_N) and change in speed error ($d(E_N)/dt$) are taken as the two input for the fuzzy controller. For this, a three-member as well as a five-member rule base is devised. The rule base for three and five membership function is shown in Tables I and II respectively.
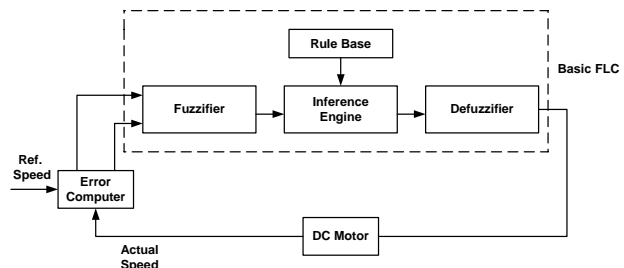

Fig. 3 Fuzzy logic Controller

TABLE I RULE BASE FOR THREE MEMBERSHIP FUNCTION

E_N $\dfrac{dE_N}{dt}$	N	Z	P
N	N	N	N
Z	Z	Z	P
P	P	P	P

TABLE II RULE BASE FOR FIVE MEMBERSHIP FUNCTION

E_N $\dfrac{dE_N}{dt}$	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NL	NS	ZE	PS	PL
PS	NS	ZE	PS	PS	PL
PL	ZE	PS	PL	PL	PL

D. Neuro-Fuzzy Controller

The proposed scheme utilizes Sugeno-type Fuzzy Inference System (FIS) controller, with the parameters inside the FIS decided by the neural-network back propagation method. The ANFIS is designed by taking speed error (E_N) and change in speed error ($d(E_N)/dt$) as the inputs. The output stabilizing signals is computed using the Fuzzy membership functions depending on these variables. ANFIS-Editor is used for realizing the system and implementation.

In a conventional fuzzy approach the membership functions and the consequent models are fixed by the model designer according to a prior knowledge. If this set is not available but a set of input-output data is observed from the process, the components of a fuzzy system (membership and consequent models) can be represented in a parametric form and the parameters are tuned by neural networks. In that case the fuzzy systems turn into neuro-fuzzy system. A fuzzy system can explain the knowledge it encodes but can't learn or adapt its knowledge from training examples, while a neural network can learn from training examples but can not explain what it has learned. Fuzzy systems and neural networks have complementary strengths and weaknesses. As a result, many researchers are trying to integrate these two schemes to generate hybrid models that can take advantage of strong points of both.

Steps to design HNF Controller

i. Draw the Simulink model with FLC and simulate it with the given rule base.

ii. The first step to design the HNF controller is collecting the training data while simulating with FLC.

iii. The two inputs, i.e., ACE and d(ACE)/dt and the output signal gives the training data.

iv. Use *anfisedit* to create the HNF .fis file.

v. Load the training data collected in Step.1 and generate the FIS with *gbell* MF's.

vi. Train the collected data with generated FIS upto a particular no. of *Epochs*.

III. RESULTS AND DISCUSSIONS

In order to validate the control strategies as described above, digital simulation were carried out on a converter dc motor drive system whose parameters are given in Appendix. The MATLAB/SIMULINK model of system under study with all four controllers is shown in Figs. 4-6.

First a comparison has been made between the performance of P-I and I-P controller. The response of the drive system is obtained by setting the reference speed to 1500 r.p.m. The system response is shown in Figs. 7-8. In Figs. 7-8 the response with P-I controller is shown with dotted line (legend P-I Controller) and the same with I-P controller is shown with solid lines (legend I-P Controller). It is clear from Figs. 7-8 that the I-P controller performs slightly better than the P-I controller. The performance of both the controller is also tested by applying a large step change in the reference speed (from 1500 rpm to 1400 rpm. At t = 1 sec). The system response for the above case is shown in Figs. 9-10 from which it is clear that I-P controller performs slightly better than the P-I controller. The performance of two fuzzy based controllers is compared by setting the reference speed to 1500 r.p.m from the initial condition. The results are shown in Figs. 11-12. It can be seen from Figs. 11-12 that the Neuro-fuzzy controller performs slightly better than the fuzzy controller.
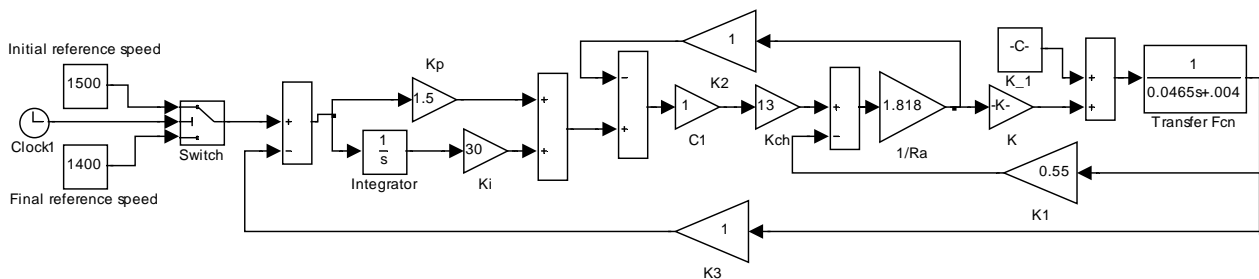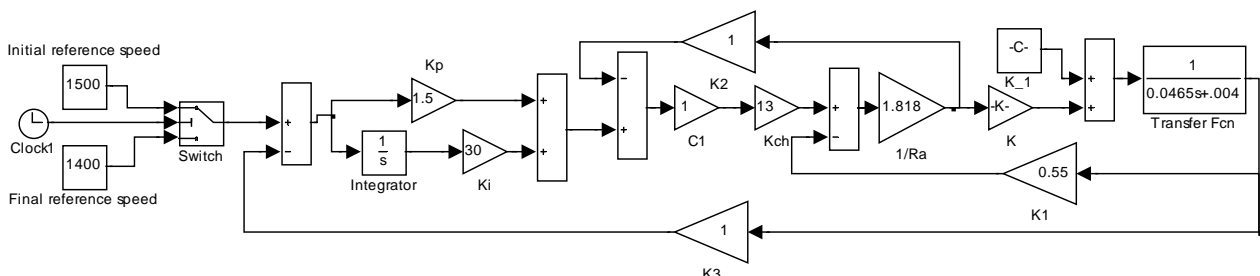

Fig. 4 MATLAB/SIMULINK Model for P-I Controller

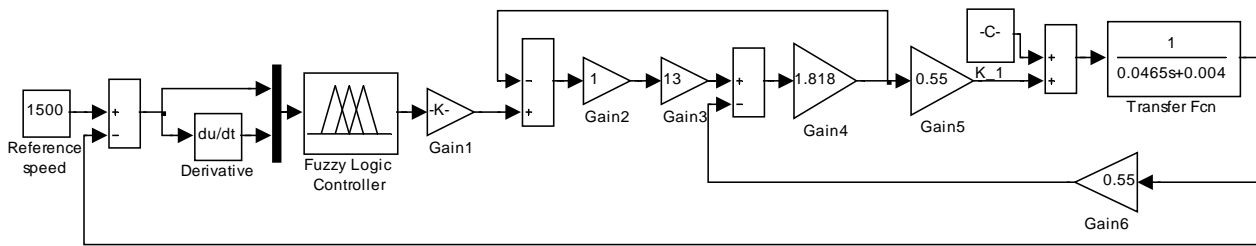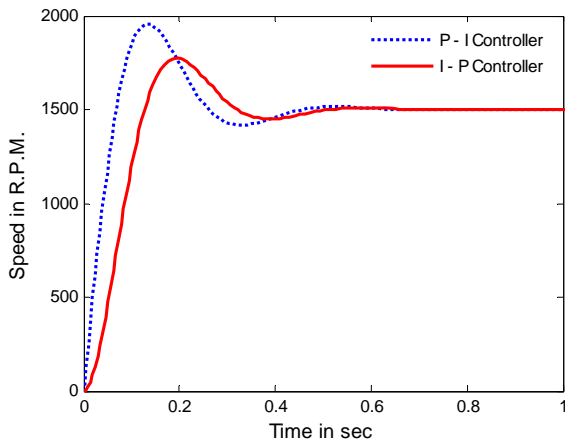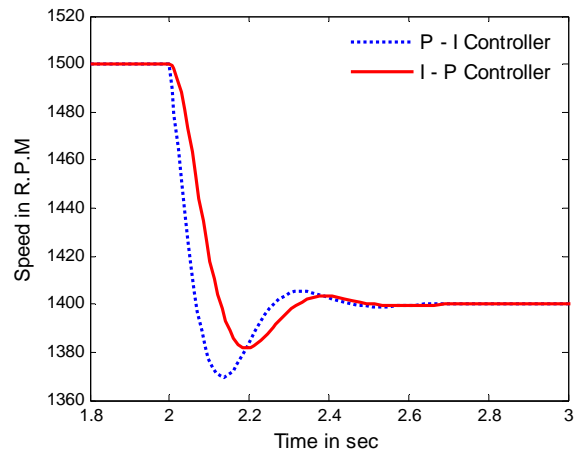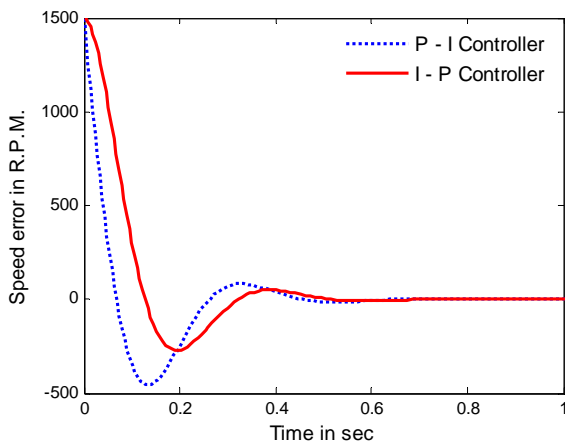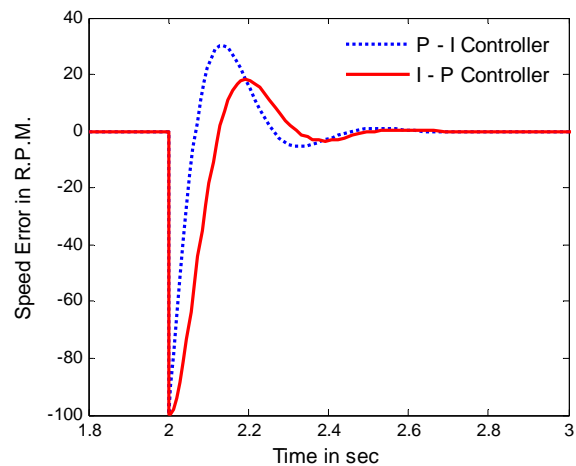Fig. 5 MATLAB/SIMULINK Model for I-P Controller

Fig. 6 MATLAB/SIMULINK Model for fuzzy and neuro-fuzzy Controller

Fig. 7 Speed response with P-I and I-P Controller (N_{ref}=1500 r.p.m)

Fig. 9 Speed response with P-I and I-P Controller (N_{ref}=1400 r.p.m)

Fig. 8 Speed error with P-I and I-P Controller (N_{ref}=1500 r.p.m)

Fig. 10 Speed error with P-I and I-P Controller (N_{ref}=1400 r.p.m)

Comparing the Fuzzy and Neuro-fuzzy controllers, the results show a slight change as shown in Figs. 11 and 12. In spite of the advantages in fuzzy control, the main limitations are the lack of a systematic design methodology and the difficulty in predicting stability and robustness of the controlled system. A trial-and-error iterative approach is taken for the controller design due to which we get sluggish response.

The neuro-fuzzy learning incorporates the architecture of neural network based fuzzy inference system. A given training data set is partitioned into a set of clusters based on subtractive clustering method. This is fast and robust method to generate the suitable initial membership functions and rule base. A fuzzy if-then rule is then extracted from each cluster to form a fuzzy rule base from which a fuzzy neural network is designed. Then a hybrid learning algorithm is used to refine the parameters of fuzzy rule base.
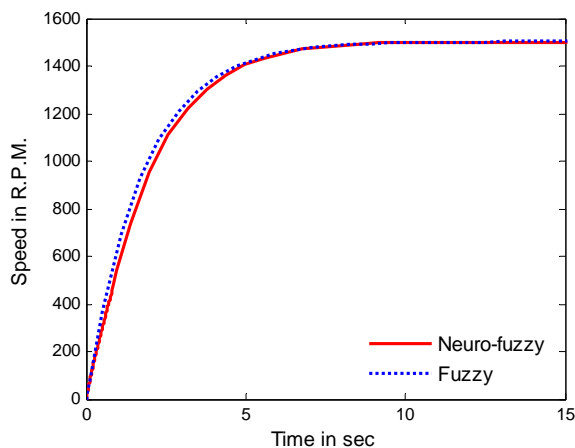
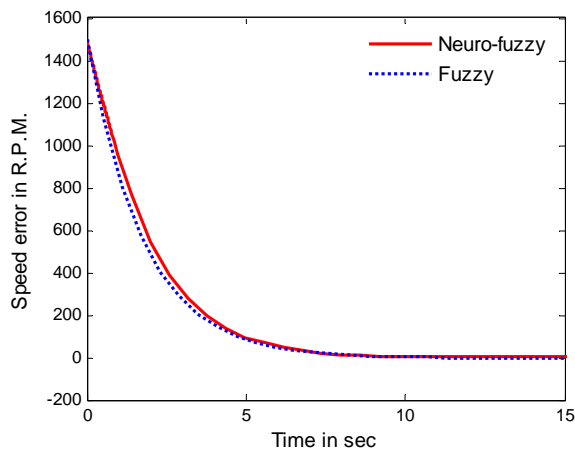Fig. 11 Speed response with Neuro-fuzzy and Fuzzy Controller

Fig. 12 Speed response with Neuro-fuzzy and Fuzzy Controller

IV. CONCLUSION

This paper is intended to compare the four controllers namely, P-I, I-P, Fuzzy and Neuro-Fuzzy controller for the speed control of a phase-controlled converter dc separately excited motor-generator system. I-P controller's performance was compared with that of conventional P-I controlled system. It is observed that I-P controller provide important advantages over the traditional P-I controller like limiting the overshoot in speed, thus the starting current overshoot can be reduced. The paper also demonstrates the successful application of fuzzy logic control and neuro-fuzzy control to a phase controlled converter dc motor drive. Fuzzy logic was used in the design of speed controllers of the drive system, and the performance was compared with that of neuro-fuzzy controller. The performance of the two fuzzy-based controller are compared and it is ovserved that the performance of Neur-fuzzy controller is slightly better than that of conventional fuzzy controller. The advantages of the Neuro-Fuzzy controller are that it determines the number of rules automatically, reduces computational time, learns faster and produces lower errors than other method. By proper design a Neuro-Fuzzy controllers can replace P-I, I-P and Fuzzy controllers for the speed control of dc motor drives.

Motor's Parameters
The motor used in this experiment is dc separately excited, rating 2.5hp at rated voltage 110 V, and the motor's parameters are as follows:
Armature resistance (R_a)   = 0.6 Ω
Armature inductance (L_a)   = 8 mH
Back e.m.f constant (K)   = 0.55 V/rad/s
Mechanical inertia (J)   = 0.0465 kg.m^2
Friction coefficient (B)   = 0.004 N.m/rad/s
Rated armature current (I_a) = 20 A

REFERENCES

[1] J.P.K. Nandam, and P.C. Sen, "A comparative study of proportional-integral (P-I) and integral-proportional (I-P) controllers for dc motor drives," Int. Jour. of Control, Vol. 44, pp. 283-297, 1986.
[2] Yodyium Tipsuwan and Mo-Yuen Chow, "Fuzzy Logic microcontroller implementation for DC motor speed control", IEEE Trans. Power Electronics, Vol. 11, No.3, pp 1271-1276, 1999.
[3] K.B. Mohanty, "Fuzzy remote controller for converter dc motor drives", Paritantra, Vol. 9, No. 1, June 2004.
[4] Thiang and Andru Hendra Wijaya, "Remote fuzzy logic control system For a DC motor speed control", Jurnal Teknik Elektro, Vol. 2, No. 1, pp. 8 – 12, 2008.
[5] S. Yuvarajan, Abdollah Khoei and Kh. Hadidi, "Fuzzy logic DC motor controller with improved performance", IEEE Trans. Power Electronics, Vol. 11, No.3, pp 1652-1656, 1998.
[6] 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", Proceedings of International Conference on CONTROL (Conference Publication No. 455, UKACC) 98, 1-4 September 1998, pp 1146-1150.
[7] Gilberto C.D. Sousa, and Bimal K. Bose, "A fuzzy set theory based control of a phase-controlled converter dc machine drive", IEEE Trans. Industry Applications, Vol. 30, No. 1, pp. 34-43, 1994.

Swasti Ranjan Khuntia was born on November 23, 1986. Currently, he is with Electrical & Electronics Engineering Dept. at National Institute of Science & Technology, Berhampur, Orissa.

K.Barada Mohanty is currently working as an Assistant Professor at NIT, Rourkela. He received the both M.Tech and Ph.D. from IIT Kharagpur and B. Sc. Engg. From U.C.E. Burla. His area of interest are Power Electronics and Control of Electrical Machines, Application of Fuzzy & Neuro Controllers.

Sidhartha Panda is working as a Professor at National Institute of Science and Technology (NIST), Berhampur, Orissa, India. He received the Ph.D. degree from Indian Institute of Technology, Roorkee, India in 2008, M.E. degree in Power Systems Engineering from UCE, Burla in 2001 and B.E. degree in Electrical Engineering in 1991. His areas of research include power system transient stability, power system dynamic stability, FACTS, optimization techniques, model order reduction, distributed generation, image processing and wind energy.

C. Ardil is with National Academy of Aviation, AZ1045, Baku, Azerbaijan, Bina, 25th km, NAA