Proceedings of the 2012 International Conference on
Advanced Mechatronic Systems, Tokyo, Japan, September 18-21, 2012

Utilizing Azadi Controller to Stabilize the Speed of a DC Motor

Sassan Azadi[1], Mosa Nouri[2]
Department of Electrical Eng., Semnan University, Semnan, Iran[1],
sazadi@semnan.ac.ir azadieng@yahoo.com
Islamic Azad University, Science and Research Branch, Tehran, Iran[2],
nuori electronic@yahoo.com

***Abstract*— Positive feedback gain is an essential part of the Azadi Controller. To assure the stability for the plant, two negative gains are used like two wings of a bird. These three different gains work together, and adapt to the system variations or system disturbances. In this paper, we utilized this controller for a DC motor, and compared the work with a conventional controller, i.e. PID. We performed the task with a microcontroller. Then, we illustrated that this controller have much better performance than the PID controller. The three parameters of the PID controller and Azadi controller can provide a fair competition in this regard. The experimental results indicate that this controller is very adaptable to the load variations. Therefore, Azadi controller can be a recommended controller for many plants.**

Keywords— **Azadi, adaptive, control, DC motor, Positive feedback**

I. INTRODUCTION

CONTROL of plants with varying dynamics is one of the great concerns of control engineers. A simple classic controller is PID or lead-lag controller could be one of the best candidates for automatic control systems [2-6], & [11-14], & [18]. The three coefficients of this controller makes the design very straight forward. However, when the plant dynamic varies, or the system encounters with a disturbance, this controller might not performance well. To overcome this problem, many researchers suggested some direct or indirect adaptive controllers. They also suggested associating some of their controller with some of the classical controllers. Computing and adjusting these adaptive gains may also become a difficult task. Therefore, many scientists aimed toward a simple controller. A scientist named Zadeh proposed the fuzzy controller [1]. This controller later on merged with some of other controllers to make it adaptive [2], [6], [7], [9], & [14]. Therefore, the complexity of controller computations, again, was started. The time needed to adjust the controller parameters was time consuming. Also, in many cases was not useful to rapidly adapting to the plant variations.

An expert named Sassan Azadi proposed a simple adaptive controller [15-17]. This controller was inspired from the nature since action potential produced by cells has one strong positive feedback surrounded two other negative feedbacks. This positive feedback gain is responsible for suppressing the system oscillations. In fact when the system starts to oscillate, the positive feedback gain generates a strong break to suppress the vibrations.

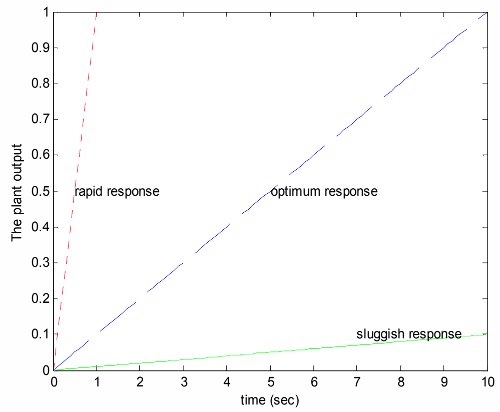


Figure 1: Three different plant response, sluggish response (the rate of error is very small), optimum response (the rate is reasonable), and very rapid response (rate of error is high and may produce overshoots and oscillations).

This positive feedback gain is surrounded with two other negative feedback gains to provide the system stability.
The performance of this controller is unbelievably great. The advantage of this controller is:

- ✓ Simple design since it has just three parameters.
- ✓ Result in lack of oscillations or overshoots for the plants.
- ✓ Adapt to the system variations.
- ✓ Produce similar responses (simple lag) for all of the plant variations.

In the following section, we present the controller model, and then we applied this controller using an At 32 microcontroller for motor speed control.

II. THE CONTROLLER MODEL

Figure 1 shows three different plant responses. One response is very sluggish, one response is very fast and my provide overshoots and oscillations, and the last one is the optimum which is not too sluggish or fast. The two parameters which are important for the system responses are error, and its derivative. Based on these two values, the controller should change its output to have a good control for the plant. The parameter which is important for the controller is the absolute value of error divided by the error derivative, i.e.:

$$v = \left|\frac{e(t)}{e'(t)}\right| \qquad (1)$$

In which the controller parameter, *v* is a function of error, *e(t)*, and its derivative *e′(t)*. Let us define a hyperbolic function for this controller as:

$$f(\upsilon) = \frac{\sum_{i=0}^{n} \alpha_i \upsilon_i}{\sum_{i=0}^{n} \beta_i \upsilon_i} \qquad (2)$$

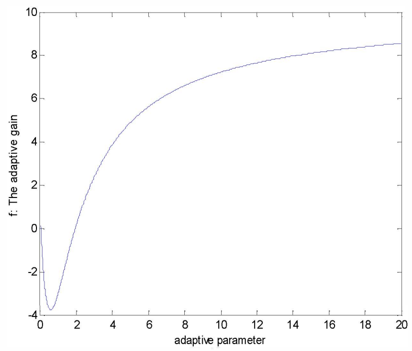


Figure 2: The function $f(v)$ verses v for some arbitrarily values of $\alpha_0=1$, $\alpha_1=20$, and $\alpha_2=10$. Since the value of α_1 provide a positive feedback, this function gets a negative value in the vicinity of $v=0$.

In which α_i and β_i are simple coefficients for the controller. For simplicity, and clarifying the point, let's consider a simplified first order controller with just three coefficients as:

$$f(\upsilon) = \frac{\alpha_0 - \alpha_1 \upsilon + \alpha_2 \upsilon^2}{1 + \upsilon + \upsilon^2} \qquad (3)$$

The three coefficients α_0, α_1, and α_2 play different acts based on the system behaviors. Figure 2 shows a simple response of three values of these coefficients.

Therefore, output of Azadi controller (except the augmented compensator) is:

$$Azadi\ controller\ output = f(\upsilon).e(t) \qquad (4)$$

As shown in this figure, the start-up value is α_0, and the end-up value is α_2. The positive feedback gain, i.e. works in the midway region. The minimum value of the $f(v)$ function can be found by setting derivative of $f(v)$ to zero, i.e. when:

$$\frac{df(\upsilon)}{d\upsilon} = 0 \qquad (5)$$

$$\upsilon_0 = \frac{-(\alpha_2 - \alpha_0) + \sqrt{\Delta}}{\alpha_2 - \alpha_0} \qquad (6)$$

In which υ_0 is the value υ when $f(v)$ is minimum. The value of Δ is:

$$\Delta = \alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_0\alpha_1 + \alpha_1\alpha_2 - \alpha_0\alpha_2 \quad (7)$$

Then the minimum value of $f(v)$ is:

$$\min \quad f(\upsilon) = f(\upsilon_0) = \frac{\alpha_0 - \alpha_1 \upsilon_0 + \alpha_2 \upsilon_0^2}{1 + \upsilon_0 + \upsilon_0^2} \qquad (8)$$

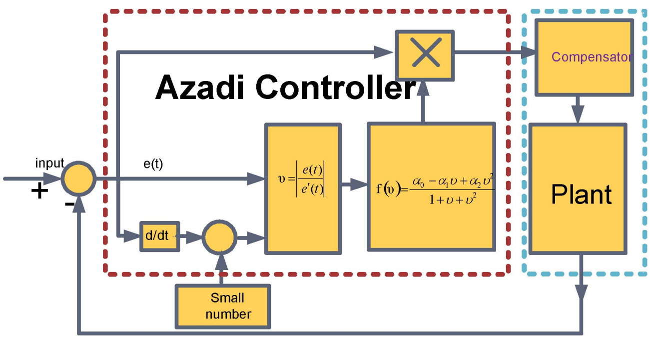


Figure 3: Azadi Controller model

As shown in figure 2, the value of $f(\upsilon_0)$ can be negative (positive feedback). In the design work, the variable gain $f(\upsilon)$ varies from:

$$f(\upsilon_0) \le f(\upsilon) \le \alpha_2 \qquad (9)$$

In order to have the plane stable for all of the plant variations, the plant should be stable for this range of $f(\upsilon)$. This condition is very conservative because a positive feedback is transient, and takes place in a small portion of time. Therefore, stability study for this design is very simple. We have to assure the stability for a gain variation. Figure 3 shows the block diagram of this controller together with the plant. As shown in this figure, a compensator is added to stabilize the plant for the variable gain of Azadi controller. This compensator can be just an integrator to provide increase the type of plant. A small number, i.e. 1e-10 was added for the start-up to avoid dividing to zero.

As shown in figure 2, the positive feedback gin is surrounded by two strong negative feedbacks. Utilizing a positive feedback gain, surrounded by two other negative feedbacks was inspired from nature. In the next chapter, we presented the idea of design.

III. THE IDEA OF DESIGN

The idea of positive feedback is a common case of neurophysiology in which action potential is produced. The action potential produced the nerve cells can be expressed as [8].

$$E_k = \frac{RT}{Z} ln \frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o} \qquad (10)$$

In this equation, E_k is the membrane potentials, R is the gas constant, T the temperature, in degree Kelvin, Z the valence, F the Faraday constant, *[K]*, *[Na]*, and *Cl* are potassium, sodium, and chloride, respectively. The "$P_{(K,\ Na,\ or\ Cl)}$" stands for the permeability, and subscribe of "*i*", and "*o*" stands for Cytoplasm, and Extra-cellular fluid, respectively. Substituting the values for the *[K]*, *[Na]*, and *[Cl]* concentrations for the above equation, we obtain:

$$E_k = 26 ln \frac{P_K 20 + P_{Na} 440 + P_{Cl} 52}{P_K 400 + P_{Na} 50 + P_{Cl} 560} \qquad (11)$$

The value of P_{Na} changes from 0.04 to 20 during action potential production.

The term of positive feedback is acceptable for the neuroscientists, and they consider the Na gain to produce phenomenon [8-9]. The *Na* permeability increases by 0.04 to 20 value during the action potential production. This positive feedback, i.e. Na channel is confined between two negative feedbacks which are *Cl*, and *K* channel. The *K* channel acts is the steady-state, and *Cl* channel may sharpen the action potential spikes.

The author now concludes that the adaptive controller should be used somehow in the nerve cells since the effects of any action is by these three well-known terms, i.e. *K*, *Na*, and *Cl* channel. The change of adaptive gain by the two negative feedbacks, and one positive feedback causes a good control for the overall system.

If this assumption is true, then the controller may be a candidate of modeling the nature behavior. Since the nature always stays at the optimum design point, inspiring this nature makes the controller be simple, and effectively. The idea comes from nature from the field of neuroscience and also was inspired from the nature.

In the following section, we applied this Azadi controller for a DC motor, and compared this control with a PID controller. In order to show the adaptability of Azadi controller, we exerted random loads to the motor. These random loads were applied to a generator coupled to the motor.

IV. TUNING AZADI CONTROLLER PARAMETERS

The *f (v)* in fact is a nonlinear gain, and can be inspected easily. This function should be designed with care. The nonlinear gain should stabilize the plant. Although, the α_2 value is a very important parameter at the end of responses, the system should not be lost in the transient behaviors. In order to show the conditions for *f (v),* let's present two simple unstable and stable systems:

$$G_{stable} = \frac{1}{s+1} \tag{12}$$

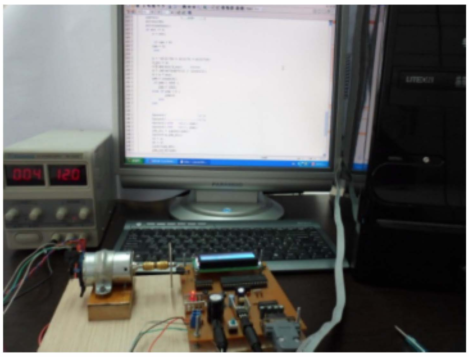
$$G_{unstable} = \frac{1}{s-1} \tag{13}$$

In the first system, since the system is stable, the *f (v)* can take the values more than -1, while in the second system since the system is unstable, *f (v)* cannot be negative. Although the negative value for the stable system is transient, and can be values less than -1, we use the conservative values for it, and put the restriction of the gain greater than -1. For the stable system, the *f (v)* cannot be negative since in the transient approach, the system might be lost. In both cases, the *f (v)* function can provide good results. Therefore, for stable systems, the values for making the system unstable, is a value for the bottom value of the *f (v)* function. For unstable systems, the *f (v)* function cannot be negative, and the upper end of *f (v)* function (i.e., α_2 value) should secure the system to be stable. We also can use a compensator to add the plant in order to stabilize the plane for some of *f (v).*

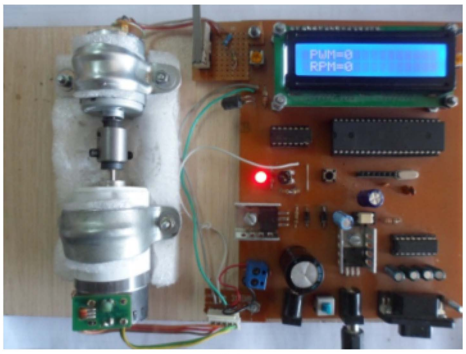
Now, let's clarify the three coefficients α_0, α_1, and α_2 effects in table I. We have to work with these three confidents together. At the beginning, we have to find the stable region of the plant. If the plant needs some compensators to be stable, we have to perform it. Then, we have to find the steady-state of error. This coefficient is determined by the α_2. After determining this coefficient, we have to obtain a fast response without any oscillations. This is done mostly by the positive feedback coefficient, i.e. α_1. If the response is very sluggish, we should reduce this positive feedback gain. Increasing of these coefficients many produce some instability for the plant.

TABLE I
COEFFICIENTS DESCRIPTIONS AND DEFINITIONS

Symbol	Defines	Description
α_0	Start-up	Defines the starting work of process. This coefficient does not participate on the response as much as the other two coefficients.
α_1	Break or Damper	Defines the break, when the response is oscillatory, it should be increased to damp the oscillation. When the plant becomes unstable, reduce it to put the system in a safe region. When the response is sluggish, we have to decrease this coefficient to speed-up the response or work with the other two coefficients.
α_2	End-up	The system should be stable for this coefficient. Increasing this coefficient reduces the steady-state of error. For a type 1 plant, α_2 is the steady-state velocity coefficient. When we want to reduce the steady-state error, we have to increase this coefficient. If this increase disturbed the transient behavior, we have to work with α_1 (or α_0)



(a)



(b)

Figure 4: View of the experimental setup for the controller and computer setup a) Microcontroller, and computer, and b) top view of the microcontroller with the motor, generator, and loads.

Tuning the three coefficients is very straight forward. Similar to the three coefficients of the PID, each coefficient have certain effect on the process.

V. EXPERIMENTAL METHOD

We applied the adaptive controller, or PID controller on Matlab [10]. The outputs and inputs of controller were linked with the At 32 microcontroller. The output of Microcontroller is transferred to the DC motor. Figure 4 shows the experimental setup of our experimental work. An encoder is coupled to the DC motor to compute the speed of motor. The motor also is coupled to a generator in order to load the motor with some variable loads.

TABLE I
THE TRANSFER FUNCTION PARAMETERS

rpm	Km	τ1	τ2
1000	23	0.03	7e-3
1500	20	0.026	2e-6
2000	19	0.028	1e-6

VI. MODEL OF A DC MOTOR

DC motors are widely used in industrial and domestic equipment. The control of the position of a motor with high accuracy is required. The electric circuit of the armature and the free body diagram of the rotor are shown in figure 5.
In this paper a DC motor is controlled via the input voltage. The dynamics of a DC motor may be expressed as [2]:

$$E_a = R_a I_a + L_a \frac{dI_a}{dt} + E_b \qquad (14)$$

$$T = J\frac{d\omega}{dt} + B\omega - T_l \qquad (15)$$

$$T = K_T I_a \qquad (16)$$

$$E_b = K_b \omega \qquad (17)$$

$$\frac{d\omega}{dt} = \varphi \qquad (18)$$

With the following physical parameters:
E_a: The input terminal voltage (source), (v);
E_b: The back emf, (v);
R_a: The armature resistance, (ohm);
I_a: The armature current (Amp);
L_a: The armature inductance, (H);
J: The moment inertial of the motor rotor and load, (Kg.m2/s2);
T: The motor torque, (Nm)
T_l: The load torque, (Nm)
ω: The speed of the shaft and the load (angular velocity), (rad/s);
φ: The shaft position, (rad);
B: The damping ratio of the mechanical system, (Nms);
K_T: The torque factor constant, (Nm/Amp);
K_a : The motor constant (v-s/rad).
Block diagram of a DC motor is shown in figure 6.

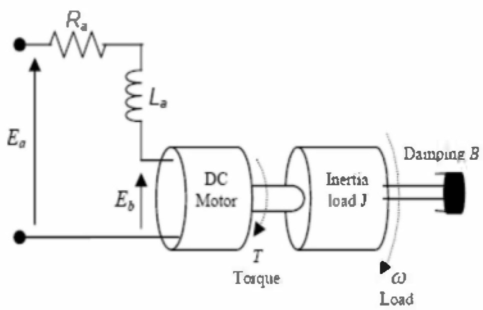


Figure 5: The schematic diagram of a DC motor

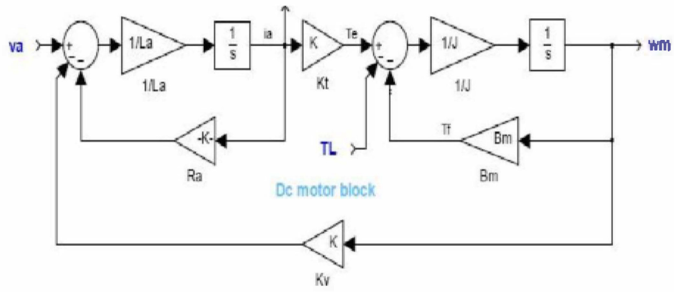


Figure 6: The block diagram of a DC motor

The DC motor used in this research work is a small 12 volt coupled to a generator. In order to find the motor dynamics, we applied different inputs, and then obtained the best transfer function based on "fminsearch" Multidimensional unconstrained nonlinear minimization (Nelder-Mead) least square method in Matlab [10]. The following table shows these transfer functions which are second orders similar to:

$$G(s) = \frac{output(rpm)}{input(volt)} = \frac{K_m}{\tau_2 s^2 + \tau_1 s + 1} \qquad (19)$$

In the following section, an adaptive controller together with a PID controller is designed.

VII. CONTROLLER PARAMETERS

Based on the table II, we considered a PID controller as:

$$K_{PID}(s) = 0.225\frac{0.0007s^2+0.03s+1}{s} \qquad (20)$$

This controller was one of the best PID controllers because the dominant poles of the system were cancelled out. We can use a PID controller for other values of table II. However, this may have causes instabilities for the plant.

Therefore, with bilinear transform, and having the sampling of 0.1 s, we have:

$$K_{PID}(z) = \frac{0.02+0.016z^{-1}+0.0076z^{-2}}{1-0.0004z^{-1}-z^{-2}} \qquad (21)$$

Now, for Azadi controller, we have the adaptive gain as:

$$f(\upsilon) = \frac{0.0225-0.112\,\upsilon+0.225\,\upsilon^2}{1+\upsilon+\upsilon^2} \qquad (22)$$

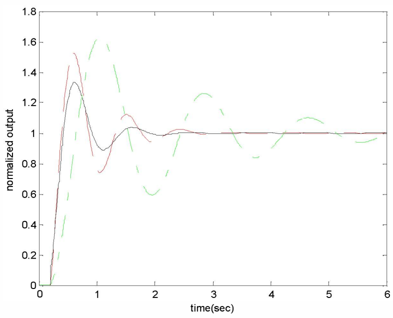
In this equation, the ratio of α_2 to α_1 is ten folds, and the ratio of α_2 to $-\alpha_1$ is five folds. These values are good enough to have a stable region for system parameters, and have good static velocity error coefficient. In order to have zero steady-state error, we considered an integrator for the compensator added to the plant. Therefore:

$$Compensator \quad output = \int f(\upsilon) \qquad (23)$$

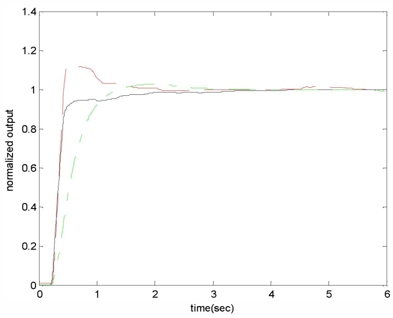
Because the adaptive gain is just a gain, adding an integrator to the controller, provides steady-state zero for step inputs. The K_v system equals to α_2 multiplied by the plant gain (which is variable). Both of the PID and adaptive controller K_v are the same. Therefore, comparisons of these controllers are almost fair. In the next section, we presented the experimental results obtained for both of these controllers.

VIII. PRACTICAL RESULT

In this section, we present the results for Azadi, and PID controllers. First, we simulated both of the controllers on Matlab with the plant model based on table II. Figure 7 shows the results obtained for these controllers. We present the normalized responses based on this table. In figure 7a, the PID controllers provide some oscillations with high values of overshoots. While Azadi controller, as shown in figure 7b, has moderate overshoots or oscillations.



(a)



(b)

Figure 7: The normalized simulation results based on table II for a) PID controller, and b) Azadi controller

A step of 1000 rpm and 2000 rpm is applied to the motor. Then, the motor which is coupled to a generator encounters to some random variable loads.

Figure 8 shows the step (of 1000 rpm) response of this DC motor for PID controller with and without variable loads. Figure 9, also shows the step (of 2000 rpm) response for the same controller with and without variable loads. Figure 10 shows the step (of 1000 rpm) response of the same conditions as figure 8 for Azadi controller. Figure 11 shows the step (of 2000 rpm) response of the same conditions as figure 9 for Azadi controller.

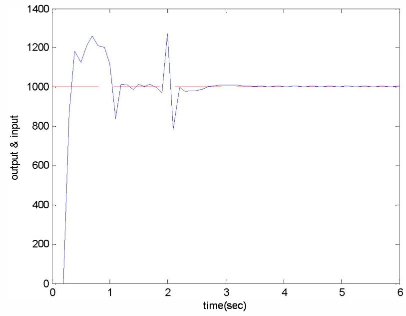


Figure 8: Step response of the motor for the PID controller. The input step is 1000 rpm.

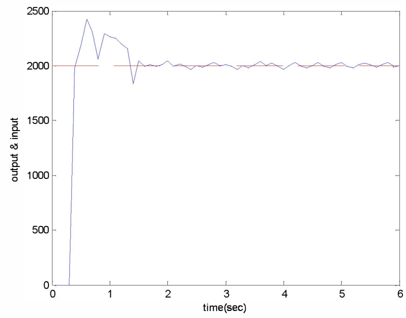


Figure 9: Step response of the motor for the PID controller. The input step is 2000 rpm.

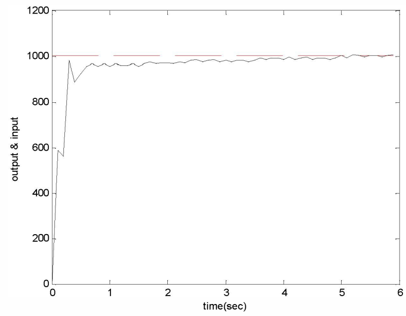


Figure 10: Step response of the motor for the adaptive Azadi controller. The input step is 1000 rpm.

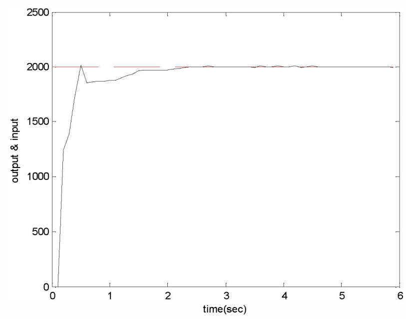


Figure 11: Step response of the motor for the adaptive Azadi controller. The input step is 2000 rpm.

In the next section, we present a brief discussion about the results obtained for this section.

IX. DISCUSSION

Azadi controller has three parameters similar to a PID controller. However, this controller provides better performance than the PID ones. In addition, because Azadi controller is adaptive, it can adjust an appropriate gain for the plant in the presence of any disturbances or plant variations. Comparing figure 10 to figure 8, and figure 11 to figure 9 demonstrate this claim. In addition, since Azadi controller has a strong damper or break, the overshoots of the system almost terminates in any cases of simulations. Looking at figure 11 illustrates a bend of the plant responses when reaching to the desired output (2000 rpm). This reduction of gain or reversing of the gain (positive feedback) abolishes the plant overshoots or oscillations. In figure 10, when plant reaches the desired input, controller gain changes are being seen obviously. Also, in both of the figures, when the plant face with disturbances, the controllers behaves well, and do not let the plant diverts from the desired inputs (1000 or 2000 rpm).

Tuning of Azadi controller parameters depends on the problems. The design is very straight forward. If more damping is needed, we can increase the α_1 coefficient. This increase is limited to the plant restriction of acceptable positive feedback gain. If smaller error coefficient is needed, we can increase α_2 (increase of K_v). This increase is limited to plant restriction.

The Azadi controller is very simple, and can work for a wide range of plant uncertainty. This controller, is very fast, and with small amount of computations, can adjust the necessary plant input energy in order to avoid overshoots, and oscillations. Although this controller just works with a gain, it can be used for unstable plants. In this case, first, the plant should put in a safe and stable region, then the two extremes for the gain should be determines. The amount of positive feedback used for the plant depends on how fast the system can come back to the safe place. Therefore, no matter how a system dynamic is or may changes, the controller “defines” the response of plant. This great advantage of this controller is a proud and beauty of this design. The controller was inspired from the nature, and this can show how nature can be adapted to many undesired fluctuations, and system variations. In fact, the nature does a simple play with the plant uncertainties. The computations are very few, and the responses are almost the same. The author has tried to understand the nature control, and find the key of this success. It is actually usage of a positive feedback gain which is restricted to two other negative feedbacks. Never ever this positive feedback can violates the responses since in each case, the feedback will switches to either one of the negative feedback gains.

The stability study of system with many variations also is one of the great consideration and easy computation of the controller, since, the two extremes of controller gain should put the system in the stable place. The positive feedback gain is confined to these two negative gains. The design procedure for this controller is also very simple. First, we may use a conventional controller to make the plant either stable or having zero steady-state. Then depends on how smooth we want the plant to be, we can calculate the adaptive gain. This adaptive gain has a minimum and a maximum (the coefficient of v^2). When the plant dynamic varies, the controller automatically compensates the extra increase or decrease of the plant sensitivity to assure the pre-defined dynamics. This phenomena is “not” just a design, it looks like to be a miracle!

X. CONCLUSION

We demonstrated a novel adaptive controller, which is great in many aspects. This controller is simple, and easily can be adjusted. It is also very powerful to compensate the system variations, no matter this variation is due to sensitivity changes of the system or disturbances, or some unrecognized dynamics. The important aspect of this control is that it was inspired from the nature, not simply from any human ideas.

REFERENCES

[1] Zadeh, http://www-bisc.cs.berkeley.edu/zadeh/papers .

[2] Sufian Ashraf Mazhari, Surenda Kumar, “Heuristic Search Algorithms for Tuning PUMA 560 Fuzzy PID Controller”, International Journal of Computer Science, www.waset.org, fall 2008.

[3] Jinzhu Peng, Rickey Dubay, " Identification and adaptive neural network control of a DC motor system with dead-zone characteristics”, Elsevier Accepted 23 June 2011.

[4] Kara T., Eker İ. (2004), “Nonlinear modeling and identification of a DC motor for bidirectional operation with real time experiments”, Energy Conversion and Management 2004.

[5] Bennett S. (1993), "Development of the PID controller”, IEEE Control Systems Magazine 1993.

[6] R. Nejati, R. Hoshmand, “Controller design and fuzzy-neural adaptive DC motor permanent magnet with unbalanced load”, 2007.

[7] Sassan Azadi, Hamid Reza Momeni, “Utilization of a Direct Adaptive Controller for a Cardiovascular System”, Esteghlal Journal, Isfahan, Jan, 2000.

[8] Eric R. Kandel, James H. Schwartz, “Principles of Neural Science”, Elsevier Science Publishing Company, 2000.

[9] Artur C. Guyton, “Textbook of Medical Physiology”, W. B. Saunders Company.

[10] Mathworks, Matlab Toolbox 2011.

[11] Mohsen Fallahi, Sassan Azadi, “Robust Control of DC Motor Using Fuzzy Sliding Mode Control with PID Compensator”, Journal of Applied Mechanics and Materials, pp. 3210-3214, Oct. 2011.

[12] Mohsen Fallahi, Sassan Azadi, “Fuzzy PID Sliding Mode Controller Design for the Position Control of a DC Motor”, ICETC 2009: pp73-77.

[13] Mohsen Fallahi, Sassan Azadi, “Adaptive Control of an Inverted Pendulum Using Adaptive PID Neural Network”, ICETC 2009, International Conference on Signal Processing Systems, 15-17 May 2009, pp. 589 – 593, Singapore.

[14] Mostafa Marandi, Sassan Azadi, “Design of ac Adaptive Nero-Fuzzy Position Controller for a Pneumatic System”, Proceeding of the International Conference on Man-Machine Systems (ICoMMS), 11-13 October 2009, Malaysia.

[15] Sassan Azadi, “Presenting an Adaptive Controller Based on Positive Feedback”, ICAFS-2010, August 27-29, Prague, Czech.

[16] Sassan Azadi, “Utilizing an Adaptive Controller (Azadi Controller) for Trajectory Planning of PUMA 560 Robot”, Journal of Advanced Materials Research Vols. 403-408 (2012) pp. 4880-4887, Switzerland.

[17] Sassan Azadi, “Introducing a Simple Adaptive Controller (Azadi Controller) Based on Positive Feedbacks”, Mianyang, China, 2011 Chinese Control and Decision Conference (CCDC 2011), 23 - 25 May 2011.

[18] Mohsen Fallahi, Sassan Azadi, “Adaptive Control of a DC Motor Using Neural Network Sliding Mode Control” Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 IMECS 2009, March 18-20, 2009, Hong Kong.