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Comparing Azadi Controller with Several Optimal Controllers

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ABSTRACT

Azadi controller is an adaptive controller which utilizes positive feedback to suppress the plant oscillations. In this paper, this controller was used for some variable systems such as first order system and system with time delay, and then the results was compared with the results obtained from four different optimal controllers. These controllers are modulus hugging optimization method, symmetrical optimum method, Ziegler–Nichols tuning method, and fuzzy PID controller with phase margin of 60 degrees. The results indicated that Azadi controller in all aspects is quite better than the others**.**Since Azadi controller has just three parameters_ α0, α1, and α2_, and have much better performance than these optimal controllers, it could be suitable controller for many variable plants.

KEYWORDS: Azadi Controller, Adaptive Controller, Modulus Hugging Method, Symmetrical Method, Ziegler–Nichols, Fuzzy PID controller.

1. INTRODUCTION

Control of plants with varying dynamics is one of the greatest concerns of control engineers. A simple classic controller is PID or lead-lag controller. This controller could be one of the best candidates for automatic control systems [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12]. Having just three parameters of this controller makes the design very simple and straightforward. However, when the plant dynamic varies, or some disturbances take places, this controller encounters with many troubles. To tackle this problem, many researchers have suggested many 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 problematic task. Consequently, many scientists aimed toward somesimpler and user-friendlycontrollers. A scientist named Zadeh proposed the fuzzy controller [13]. This controller later on merged with some of other controllers to make it adaptive [6], [9], [12], [14]. Therefore, the complexity of controller computations was startedagain. Adjusting the controller parameters was time consuming. Moreover, in many cases, adapting to the plant variations rapidlywas not advantageous.

An expert named Azadi proposed a simple adaptive controller [15], [16], [17], [18]. This controller was inspired from the nature. It uses a positive feedback gain to vanish the system oscillations. Indeed, when the system starts to oscillate, the positive feedback gain generates a strong break to suppress the vibrations. This positive feedback gain is surrounded with two other negative feedback gains to ensure the system stability. In subsequent sections, performance of Azadi controller is compared with four of the best classical optimal methods such as modulus hugging optimization method, symmetrical optimum method, Ziegler–Nichols tuning method, and optimum PID based on phase margin of 60 degrees.

2. THEAZADI CONTROLLER

A. The Controller Model

Azadi controller is a function in which its parameter based on the plant error and its derivative. Actually, the two parameters which are substantial for the system responses are error, and its derivative. Based on these two values, the controller should change its output to achieve a decent control for the plant. The parameter which is significant for the controller is the absolute value of error divided by the error derivative:

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

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

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

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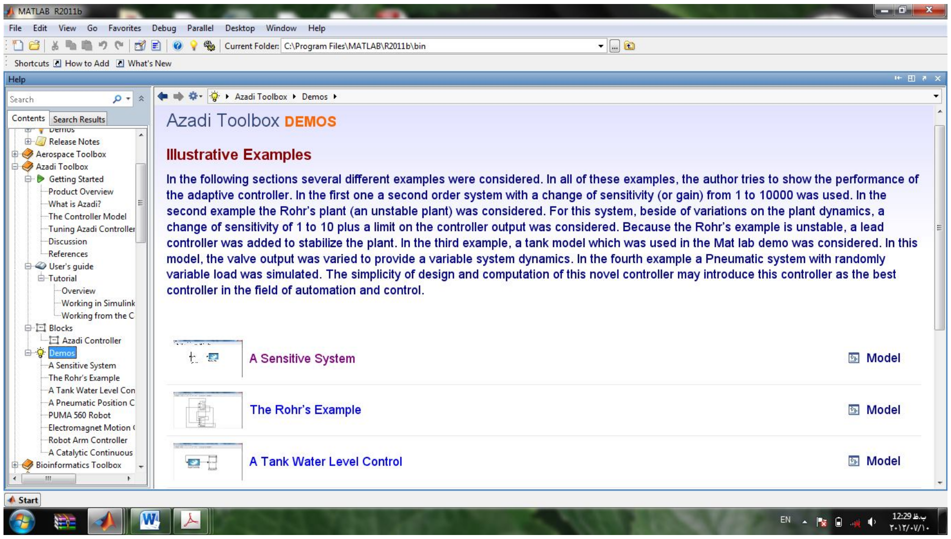

Fig.1.Azadi Toolbox (Matlab program) used for simulations of this research work

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

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

The three parameters α_0, α_1, and α_2 play different acts based on the system performances. Figure 2 demonstrates a simple response of three values of these parameters. So, output of Azadi controller (except the augmented compensator) is:

$$\text{Azadi output} = f(\upsilon).e(t) \qquad (4)$$

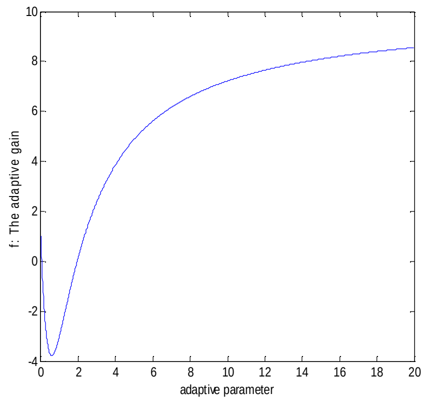

Fig.2. The function *f(v)* verses v for some arbitrarily values of α_0=1, α_1=20, and α_2=10. Since the value of α_1 provide a positive feedback, this function gets a negative value in the vicinity of v=0.

As shown in this figure, the start-up value is α_0 and the end-up value is α_2. The positive feedback gain 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:

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

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

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

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

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

Ensuring the plane be stable for all of the plant variations, it should be stable for this range of gain *f(υ)*. This condition is very conservative since a positive feedback is transient, and occurs in a small portion of time. Therefore, stability study for this design is very simple. It must be assure the stability for a gain variation.

Figure 3 illustrates the block diagram of this controller 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 such as $1e^{-10}$ was added for the start-up to avoid dividing to zero.

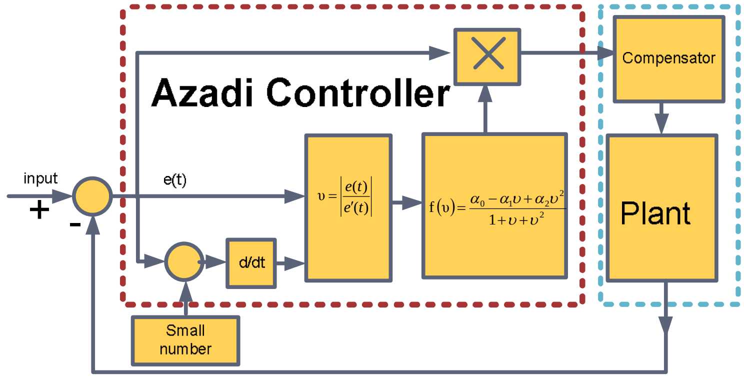

Fig.3. Azadi Controller model

In the next section the idea of design is presented. As can be seen in figure 2, the positive feedback gain 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.

B. The idea of design

The idea of positive feedback is a common case of neurophysiology in which action potential is produced [19]. The action potential produced the nerve cells can be expressed as

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

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, leads to (11) the value of P_{Na} changes from 0.04 to 20 during action potential production.

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

The term of positive feedback is acceptable for the neuroscientists, and they consider the *Na* gain to produce phenomenon [19], [20]. The *Na* permeability increases by 0.04 to 20 value during the action potential production. This positive feedback like*Na* channel is confined between two negative feedbacks which are *Cl*, and *K* channel. The *K* channel acts are 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 as can be demonstrated by for instance *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. That is why 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 next section, method of designing Azadi controller parameters is survived.

C. 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 quite important coefficient 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:

$$G_{stable} = \frac{1}{s+1} \qquad (12)$$

$$G_{unstable} = \frac{1}{s-1} \qquad (13)$$

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, it could be used 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 decent results. Thus, 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 (α_2 value) should secure the system to be stable.Also a compensator could be added the plant in order to stabilize the plane for some of *f(v)*.

Table 1 clarifies the three parameters $\alpha_{0,}\,\alpha_1$ and α_2 and its effects. At the beginning, the stable region of the plant is discovered. If the plant requires some compensators to be stable, it is performed. Then, the steady state of error is defined. This coefficient is determined by theα_2. After determining this coefficient, it is necessary 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, this positive feedback gain should be reduced. Increasing of these parameters many produce some instability for the plant.

TABLE 1
Parametersof α_0, α_1, and α_2 descriptions, and definitions

Parameters	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 parameters.
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 parameters.
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).

Tuning the three parameters is absolutely straightforward. Similar to the three parameters of the PID, each coefficient have certain effect on the process. In the subsequent section, performance of Azadi controller is compared with one classical optimal controller which is called modulus hugging optimization method.

3. Results

A. *Modulus Hugging Optimization Method*

The modulus hugging optimization method is one of the best classical optimal methods for designing controller [21]. It determines the controller parameters in order to achieve optimum working of the control system. As a good comparison, a first order system for the plant was considered as follows which T_e is the plant time constant:

$$\frac{1}{T_e S+1} \qquad (14)$$

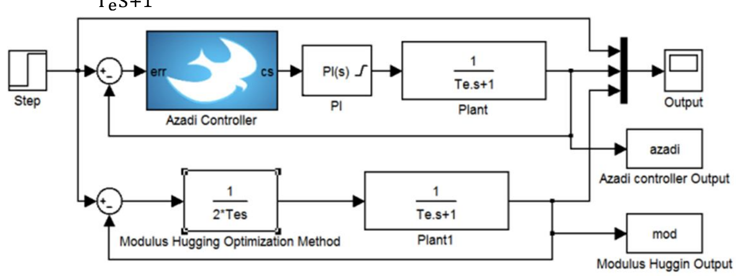

Fig.4. The Simulink model of Azadi controller and Modulus optimum method.

The Azadi controller assumes to be:

$$f(v) = \frac{0.4-v+6v^2}{1+v+v^2} \qquad (15)$$

With a PI compensator to provide the system be type one.

$$K(s) = \frac{s+1}{s} \qquad (16)$$

The zero of PI controller is not very important and can change without vital variation on the responses. Based on Modulus Hugging Optimization Method, the controller is (23) which makes the system is type one (zero steady-state error for step input).

$$K_{mod}(s) = \frac{1}{2T_e S} \qquad (17)$$

This model was run three times with three different time constant (T_e) which were 0.5 second, 1 second, and lastly 2 seconds and in figure 5,response of both controllers could be seen. This is to say that simulation time is 20 seconds, and the Azadi controller output is saturated between 15 to -15.

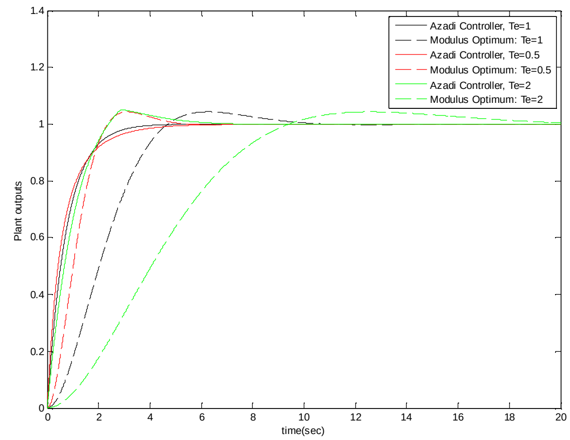

Fig.5. Response of Azadi controller and Modulus optimum controller

This is to say that modulus hugging controlleris tuned again with plant changes but Azadi controller was with constant parameters. Despite this situation results demonstrated with no cast of doubt, the performance of Azadi controller in all aspects is better than modulus hugging optimum method. Table 2 describes the results in greater details

TABLE 2
Details of Azadi controller and Modulus optimum's responses

Characteristics	Controller	Time Constant (T_e)		
		0.5 sec	1.0 sec	2.0 sec.
Overshoot	Azadi Controller	0%	0%	5.1%
	Modulus Hugging Optimization Method	4.3%	4.3%	4.3%
Settling Time (Second)	Azadi Controller	3.6 sec	3 sec	4.7 sec
	Modulus Hugging Optimization Method	4.3 sec	8.5 sec	17 sec
Rise Time (Second)	Azadi Controller	1.8 sec	1.7 sec	1.7 sec
	Modulus Hugging Optimization Method	1.9 sec	3.7 sec	7.5 sec

Apparently, percent of overshoot, settling and rise time of Azadi controller is certainly more pleasant than modulus hugging optimization method. These results prove that when dynamics of plant turns drastically Azadi controller, which is an adaptive controller, demonstrates its power and maintains proper response. In following section, performance of Azadi controller is compared the second classical optimal controller which is symmetrical optimum method.

B. Symmetrical Optimum Method

The symmetrical optimum method is another classical optimal method for designing controller[21]. It defines the controller parameters with regard to gain optimum working of the control system. As a routine comparison, a first order system for the plant was considered as:

$$\frac{1}{s(T_e s+1)} \qquad (18)$$

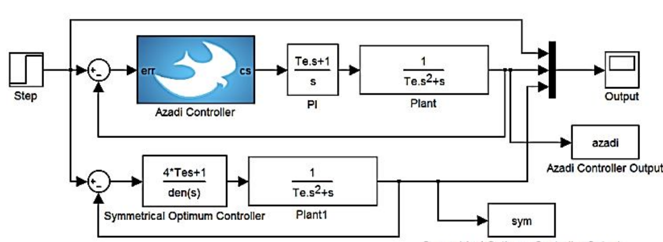

Fig.6. The Simulink model of Azadi controller and Symmetrical optimum method.

The Azadi controller assumes to be:

$$f(v) = \frac{0.4-v+6v^2}{1+v+v^2} \qquad (19)$$

With the same PI controller for just providing the steady-state errors:

$$K(s) = \frac{s+1}{s} \qquad (20)$$

The zero of PI controller is not very important and can change without vital variation on the responses.
The symmetrical optimum controller in this case is (23) which makes the type of system to be two (zero ramp responses).

$$\frac{4T_eS+1}{2T_e(4T_eS)} \qquad (21)$$

This model was run three times with three different time constant (T_e) which were 0.1 second, 1 second, lastly 2 seconds and in figure 7response of both controllersis illustrated. This is to say that simulation time is 20 secondsand to preventing apply intolerable gain to plant, Azadi controller output is saturated between 15 to -15.

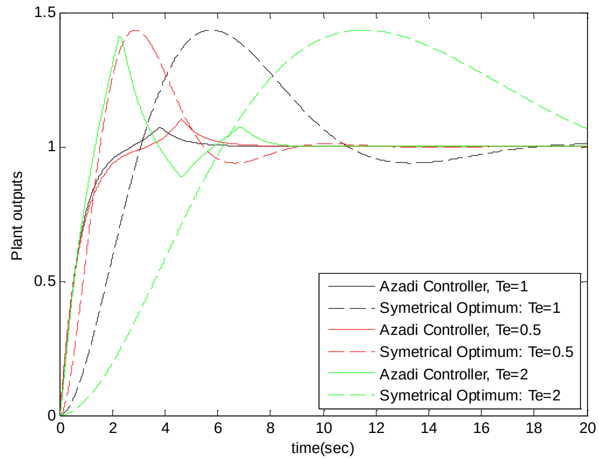

Fig.7. Response of Azadi controller and Symmetrical optimum controller

This is to say that symmetrical optimum controlleris tuned again with plant changes but Azadi controller was with constant parameters. Despite this situation results demonstrated with no cast of doubt, the performance of Azadi controller in all facets is better than symmetrical optimum method. Table 3 describes the results in greater details.

TABLE 3
Details of Azadi controller and Symmetrical optimum's responses

Characteristics	**Controller**	**Time Constant (T_e)**		
		0.5 sec	1.0 sec	2.0 sec.
Overshoot	Azadi Controller	0%	0%	41%
	Symmetrical Optimum Method	4.3%	4.3%	43%
Settling Time (Second)	Azadi Controller	3.6 sec	3 sec	4.7 sec
	Symmetrical Optimum Method	4.3 sec	8.5 sec	17 sec
Rise Time (Second)	Azadi Controller	1.8 sec	1.7 sec	1.7 sec
	Symmetrical Optimum Method	1.9 sec	3.7 sec	7.5 sec

For a second time, percent of overshoot, settling and rise time of Azadi controller is certainly more pleasant than symmetrical optimum method. These results prove that when dynamics of plant revolves drastically Azadi controller which is an adaptive controller demonstrates its power and maintains proper response. In following section, performance of Azadi controller is compared the third classical optimal controller which is Ziegler–Nichols tuning method.

C. Ziegler–Nichols Tuning Method

The Ziegler–Nichols tuning method is another classical optimal method for designing controller[22]. It states the controller parameters with regard to gain optimum working of the control system.For illustrating the Ziegler–Nichols tuning method, the plant is (22) which L is the system delay.

$$\frac{e^{-LS}}{T_eS+1} \qquad (22)$$

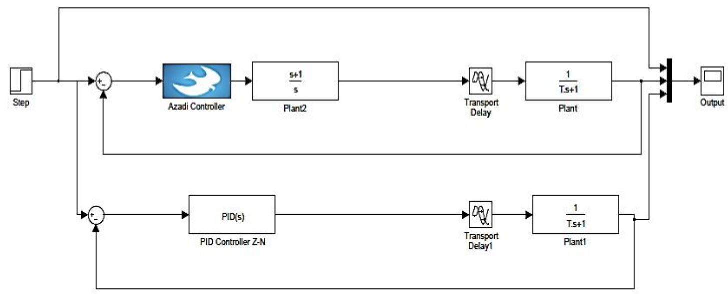

Fig.8. The Simulink model of Azadi controller and Z-N model.

The PID parameters for 20% are (22):

$$p = \frac{T_e}{2L}, \text{ I=2L, D=}\frac{L}{2} \quad (23)$$

Now consider that the Azadi controller in this case is (24) with the same PI controller as (20):

$$f(\upsilon) = \frac{0.7-3.5\upsilon+2.1\upsilon^2}{1+\upsilon+\upsilon^2} \quad (24)$$

This model was run three times with time constant (T_e) =1 and three different delay time (L) which were 0.25 second, 0.5 second, and lastly 0.75 seconds. Figure 9 illustrates response of both controllers. This is to say that simulation time is 20 seconds and to preventing apply intolerable gain to plant, Azadi controller output is saturated between 15 to -15.

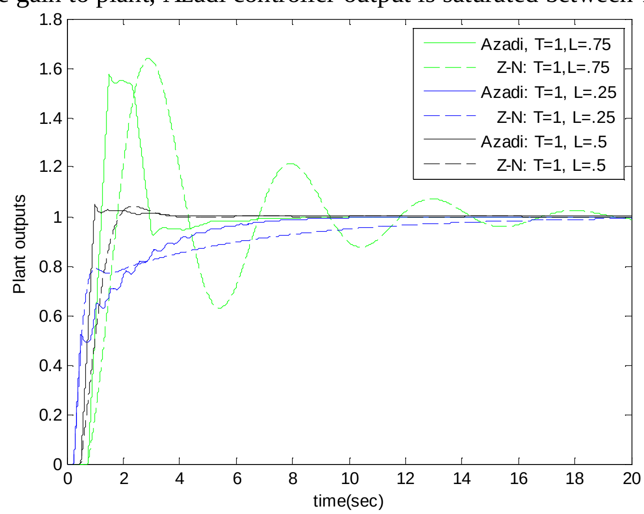

Fig.9. Response of Azadi controller and Z-N controller.

This is to say that Ziegler–Nichols controller is tuned again with plant changes but Azadi controller was with constant parameters. Despite this situation results demonstrated with no cast of doubt, the performance of Azadi controller in all facets is better than Ziegler–Nichols tuning method. Table 4 describes the results in greater details.

TABLE 4
Details of Azadi and Z-N's responses

Characteristics	Controller	L=0.75 sec	L=0.25 sec	L=0.5 sec
Overshoot	Azadi Controller	57%	0%	5%
	Ziegler–Nichols Tuning Method	64%	0%	4%
Settling Time (Second)	Azadi Controller	5 sec	7 sec	2.2 sec
	Ziegler–Nichols Tuning Method	18.5 sec	15 sec	3.0 sec
Rise Time (Second)	Azadi Controller	1.2 sec	3.9 sec	0.95 sec
	Ziegler–Nichols Tuning Method	1.7 sec	6.3 sec	6.3 sec

For a third time, Percent of overshoot, settling and rise time of Azadi controller is certainly more pleasant than Ziegler–Nichols tuning method. These results prove that when dynamics of plant revolves drastically Azadi controller which is an adaptive controller demonstrates its authority and maintains proper response. In subsequent section, performance of Azadi controller is compared the fourth optimal controller which is fuzzy PID tuning method.

D. Azadi controller and Fuzzy PID Controller:

The fuzzy PID tuning method is a recent optimal method for designing controller [23]. It states the controller parameters with regard to fuzzy logic [24], [25].Some sample of discrete plants is considered. The G (z) is based on Matlab simulation program named "sllookup table". Then, some of the poles were changed to see the adaptation of the controllers. In all of the simulations the sampling time is considered to be T_S=0.1 sec.

In this case, the Azadi controller is (25) with a PI controller such as (26):

$$f(v) = \frac{1-8v+40v^2}{1+v+v^2} \quad (25)$$

$$K(z) = \frac{0.3T_S z}{z-1} + 1 \quad (26)$$

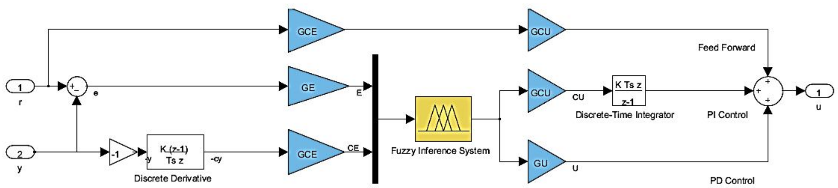

Fig.10. The Simulink model of fuzzy PID controller

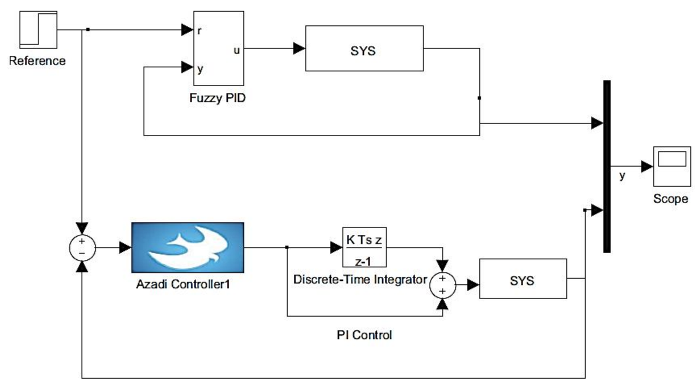

Fig.11. The Simulink model of Azadi controller and fuzzy PID controller

The optimal PID parameters with fuzzy PID are:

$$G_1(z) = \frac{0.000133(z+3)(z+.2)}{(z-0.9)(z-0.75)(z-0.6)} \quad (27)$$

$$G_2(z) = \frac{0.000133(z+3)(z+.2)}{(z-0.98)(z-0.75)(z-0.6)} \quad (28)$$

$$G_3(z) = \frac{0.000133(z+3)(z+.2)}{(z-0.9)(z-0.9)(z-0.6)} \quad (29)$$

$$G_4(z) = \frac{0.000133(z+3)(z+.2)}{(z-0.9)(z-0.75)(z-0.8)} \quad (30)$$

This model was run four times with three G (z). Figure 10 illustrates response of both controllers. This is to say that simulation time is 20 seconds and to preventing apply intolerable gain to plant, Azadi controller output is saturated between 15 to -15.

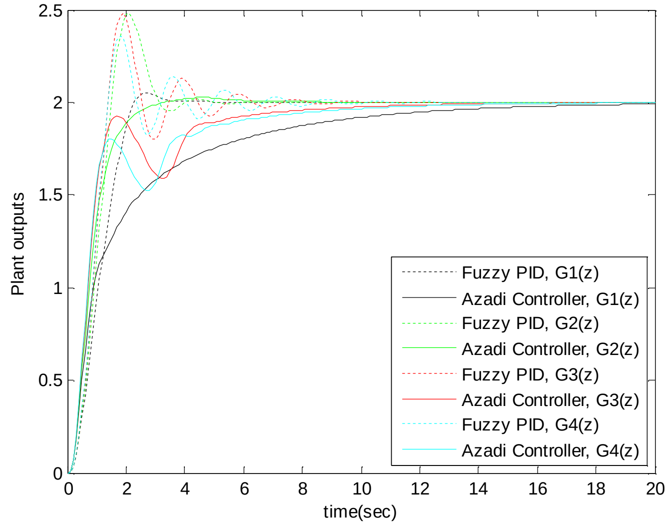

Fig. 12. Response of Azadi controller and fuzzy PID Controller

This is to say that fuzzy PID controller is tuned again with plant changes but Azadi controller was with constant parameters. Despite this situation results demonstrated with no cast of doubt, the performance of Azadi controller in all facets is better than fuzzy PID tuning method. Table 5 describes the results in greater details.

TABLE 5
Details of Azadi controller and Fuzzy PID Controller's responses

Characteristics	Controller	G_1	G_2	G_3	G_4
Overshoot	Azadi Controller	0%	1%	0%	0%
	Fuzzy PID	2.5%	23%	24%	18%
Settling Time (Second)	Azadi Controller	13 sec	2.6 sec	8 sec	9.3 sec
	Fuzzy PID	3 sec	2.9 sec	7 sec	6.3 sec
Rise Time (Second)	Azadi Controller	6 sec	1.4 sec	1.3 sec	1.2 sec
	Fuzzy PID	2 sec	1.7 sec	1.3 sec	1.2 sec

For a fourth time, percent of overshoot, settling and rise time of Azadi controller is certainly more pleasant than fuzzy PID tuning method. These results prove that when dynamics of plant revolves drastically Azadi controller which is an adaptive controller demonstrates its authority and maintains proper response.

4. CONCLUSION

In this paper, performance of a novel adaptive controller which is called Azadi controller for some ordinal systems is compared with four of the best optimal methods for designing controller such as modulus hugging optimization method, symmetrical optimum method, Ziegler–Nichols tuning method and fuzzy PID Controller. This is to say that all of abovementioned controllers were tuned again with plant variations but Azadi controller was with constant parameters. Despite this situation results demonstrated in all aspects Azadi controller is definitely better than the others. Indeed, Azadi controller is spectacular in many facets. It is simple and fast, and could be adjusted effortlessly. This controller is also very robust to compensate the *system variations* due to sensitivity changes of the system or disturbances or some unrecognized dynamics. The main aspect of this control is inspired from the nature, not simply from any human ideas.

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