JREE: Vol. 5, No. 1, (Winter 2018) 1-7

Journal of Renewable
Energy and Environment

Journal Homepage: www.jree.ir

Research Article

Stability Improvement of Hydraulic Turbine Regulating System Using Round-Robin Scheduling Algorithm

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PAPER INFO

Paper history:
Received 11 January 2018
Accepted in revised form 18 November 2018

Keywords:
Stability
Hydraulic Turbine Regulating System
Round-Robin Scheduling Algorithm

ABSTRACT

The sustainability of hydraulic turbines was one of the most important issues considered by electrical energy provider experts. Increased electromechanical oscillation damping is one of the key issues in the turbines sustainability. Electromechanical oscillations, if not quickly damp, can threaten the stability of hydraulic turbines and causes the separation of different parts of the network form each other, specifically ejecting the generators from the turbine. In this paper, a Round-robin scheduling algorithm was used based on a neural network and simulations were investigated by several methods. Thus, using the designed Round-robin scheduling algorithm, we can find three parameters simultaneously. So optimal outputs can determine by these three parameters, which would be investigated as the optimal output range. In other words, besides using other algorithms capability, it can eliminate some of their disadvantages. The Round-robin scheduling algorithm is more suitable for large and extensive systems, due to reducing the number input variables and have a non-linear and resistant structure at the same time, This algorithm can actually use for optimizing any other controlling methods.

1. INTRODUCTION

Different kinds of renewable energy, such as wind energy [1,2], solar energy [3], hybrid system energy [4] and water power [5] are widely varied in their cost-effectiveness and importance in the world [6]. More considerable point in using renewable energy is generating a little or no waste that results in minimal impact on the environment [7]. Due to frequency variations of the grid, the presence of hydropower plants was useful to control it. Hydroelectricity forces are approximating 65 % of the electrical energy produced by recycled sources, and hydroelectric power plants produce just 20 % of total energy demands[8,9]. Some advantages of hydropower plants are: having long shelf-life, low expenditure maintenance and high stability [10]. Also, the cost of produced energy was almost independent from load power factor change in hydropower plant and vice versa in the steam plant. Other benefits of a hydroelectric power station include low operation costs, eliminate costs related to fuel supply, simply switch on or in the network [2].

The proper function of a power system mainly depends on providing reliable and uninterrupted services to consumers. On the other hand, a large power system frequently undergo load power changes and disturbances such as lines or short connections. In such circumstances, the system components along with related controls can maintain the system sustainability [3]. In hydraulic turbines, because of interactions between different corresponding units, the oscillation damping debilitated the oscillatory instability intensified. In fact, different parts of the turbine may be separated from each other.finally, with the function of the protection mechanisms, the generators switched off. In previous studies, different controlling methods such as optimal control and proportional-integral-derivative (PID) controller have been used to control turbines to improve chattering effect. in addition, the limitations of optimum control and PID controller, such as sensitivity to the point of work have been fixed by controlling with the sliding-fuzzy model [4,5]. In [6], the frequency-load control for the power system in each region has been designed based on the frequency deviation of that region. So, fuzzy control is used for utilization of the adaptive algorithm parameters and minimizing the approximated errors and external disturbances effects, which guarantees the stability of the closed-loop system. In [7], Evolutionary programming (EP) was introduced for PID optimization parameters and had a convergence characteristic. This indicates the use of more controlling parameters for the PID in hydro-turbine systems. In [8], the effective and modified gravitational search algorithm has been used to identify parameters for hydraulic turbine governing systems (HTGS) with elastic impact and demonstrated HTGS parameters is a complex matrix. Thus, the tests should be evaluated with high accuracy for system improvement. The results showed that the aforementioned algorithm solved the problems caused by the parameters for nonlinear complex systems. In [9], a nonlinear mathematical model had designed for the hydro-turbine system. The theory applied in this

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system is supercritical and determines the PID controller parameters for stable and unstable regions.

Conclusions revealed that the stable range examine system under negative and positive disturbances and showed the effects of parameters on the reduction/augmentation of these negative or positive disturbances. In [10], the HTGS nonlinear model, the sliding mode controller has been designed for external disturbances with uncertainty, and the simulations have been studied in different situations. The results have shown that the sliding mode controller has more satisfactory results in compartion to the PID controller. In [20], the adaptive grid particle swarm optimization (AGPSO) with the nonlinear PID controller achievements in the system have been optimized under discharge and loading conditions. Experimental results showed that the non-linear model with AGPSO control is the best solution to get the optimal output in hydraulic turbine system compared to the traditional setting methods. In [11], a high chaotic non-linear mathematical model has been designed for Hough branching in the HTGS system. Simulation results have also shown that the convergence rate and system stability occur near the parameters. Thus, PID regulating parameters for system stability must be selected with great precision to reform the nonlinear nature of the system. In [12], a fractional-order PID controller (FOPID) has been designed for hydraulic turbine regulating system by using a non-dominated sorting genetic algorithm II (NSGAII). By analysing PID and FOPID controllers, we found that FOPID is a better design with more strength and stability to optimize the turbine system performance.

The main problem of the design was how to select the trial feedback operation, which is fixed in most cases and their selection is done through try and error process. This limits some of the outputs and also creates annoying oscillations (chattering). This approaches also provided a systematic method to select controlling operation, while the outputs obtained by these methods are still fixed. The Round-robin scheduling algorithm has been used to solve the problem by changing different conditions of the performance. To prove hydraulic system capability, it was tested in different operational conditions. The system ability to control proposed methods is depende on output results in the systems. However, testing hydraulic turbine systems are very expensive and time-consuming work. computer simulation is a fast and economical method to study hydraulic systems.

Although the use of Round-robin scheduling algorithm will be time-consuming, however, it has the ability to improve control systems and achieving the desired values. One of the most important issues in algorithm implementation, to the reason type and method of implementation, its use for any type of control systems as computational and decision-making ones. Also, the permitted range changed to build a real system are determined. Applying this method to any types of data leads to development, which helps to examine the number of parameters. It also alters the system evaluation method and examines it from other aspects. The main advantage of Round-robin scheduling algorithm is the capability to evaluate several parameters in the input and several parameters in the output simultaneously. This method provides the chance that obtained values are not solely evaluated to improve a specific parameter, but at any time of evaluation by the system, all studied parameters will be examined. In addition, if only one of the parameters needs to be examined, the same method can be used again, and only the best mode must be considered for a parameter. The output of this algorithm offers a good value for each intended parameter, meanwhile, all of these parameters will build a desirable and relatively desirable system simultaneously.

2. HYDRAULIC TURBINE

In a hydroelectric power plant, energy requirement was provided by the potential energy of water behind the dam. The produced energy depends on the volume of the water behind the dam and the difference between the height of the source and the water drained from the dam. plants classification with hydro-electric power were shown in Fig. 1 [13,14].

According to the height of the waterfall, hydroelectric power plants were classified into three groups by height: low (less than 100 m), moderate (30 meters to 100 meters) and high (more than 100 meters). Hydro-turbines contain impulse and reaction types. The difference in power and construction of different hydro-turbines strongly depend on the height of the waterfall. But they have the same response properties [15,16].

The general system model can be made by combining dynamic and unique models of duct vents, hydraulic power system, hydraulic turbine regulating system (HTRS) and a set of generators [17]. Water flows from reservoir to coil and makes the turbine to spin after passing through the system. Then, the hydro-electric generator made the engine to connect to the shaft. A governor is sued to maintain frequency and adjust the speed [18,19]. Fig. 2 shows HTRS model [30,20].

3. MATHEMATICAL MODEL

The efficiency of a hydroelectric turbine is influenced by the water columns attributes that feed the turbine. These features include the effects of water inertia, water compressibility, and elasticity of the water duct wall at the Penstock. The water inertial effect is so instantaneous that the changes in turbine water flow compared with turbine valve opening changes occur with a time delay. The wall elasticity, creating mobile waves of pressure and flow in the channel is known as the phenomenon of water hammering. By analyzing the nonlinear dynamic equations. The system equations for Integrated Model with Uncertainties (IMWU) are expressed as follows by using state-space equations [21,22]:

$$\frac{d}{dt}x_1 = x_2 + d_1 \tag{1}$$

$$\frac{d}{dt}x_2 = x_3 + d_2 \tag{2}$$

$$\frac{d}{dt}x_3 = -a_0x_1 - a_1x_2 - a_2x_3 + y + d_3 \tag{3}$$

$$\frac{d}{dt}y = \frac{1}{T_y}(u-y) + d_4 \tag{4}$$

$$\frac{d}{dt}\delta = \omega_r + d_5 \tag{5}$$

$$\begin{aligned}\frac{d}{dt}\omega_r &= \frac{1}{J_m}[b_3y + (b_0 - a_0b_3)x \\ &+ (b_1 - a_1b_3)x_2 + (b_2 - a_2b_3)x_3 - \frac{v_s}{x'_d}E'_q \sin\delta \\ &- \frac{v_s^2}{2}(\frac{1}{z_q} - \frac{1}{x'_d})\sin(2\delta) - D\omega_r] + d_6\end{aligned} \tag{6}$$

$$\begin{aligned}\frac{d}{dt}E_q &= \frac{1}{T_{do}}[E_f - E'_q - (x_d - x'_d)] \\ &+ \frac{E'_q - v_s\cos\delta}{x'_dT_{do}} + d_7\end{aligned} \tag{7}$$

where d_1 to d_7 are uncertainties (including, modeling error caused by the premise, non-linear model, internal and external turmoil), y is turbine rotation speed, δ is rotor angle, J_M is mechanical generator time constant, V_S is an infinite bus voltage, x_d is steady state reactance, x'_d is axis transient reactance, E'_q is armature distance voltage, z_q is axis orthogonal reactance, D is the damper coefficient, T_{od} is coil field time constant, E_f is actual voltage, T_y is served time constant, ω_r is rotor speed, x_1, x_2, x_3 are intermediate turbine variables. a_0, a_1, a_2, b_0 to b_3 are coefficients of equations of state, which are equal to:

$$\begin{cases} a_0 = \dfrac{24}{q_wh_wT_r^3} \\ a_1 = \dfrac{24}{T_r^2} \\ a_2 = \dfrac{3}{q_wh_wT_r} \\ b_0 = \dfrac{24m_g}{q_wh_wT_r^3} \\ b_1 = -\dfrac{24e_mm_g}{q_wT_r^2} \\ b_2 = \dfrac{3m_g}{q_wh_wT_r} \\ b_3 = -\dfrac{e_mm_g}{q_w} \end{cases} \tag{8}$$

4. PID CONTROLLER IN HTRS

At the moment, the PID controller works in a parallel way in the HTRS system. The PID controller equation is as follows:

$$u = K_P\, e + K_I \int_0^t e\,dt + K_D\,\dot{e} \tag{9}$$

in which, K_p, K_I, and K_D are the proportional, integral and derivative gains of the PID controller, respectively. The PID controller performance depends on the values of controller parameters. The solution of this problem is to use optimized techniques such as genetic algorithms [23]. In this paper, the use of Round-robin scheduling algorithm led to the improved response of PID controller in the HTRS system.

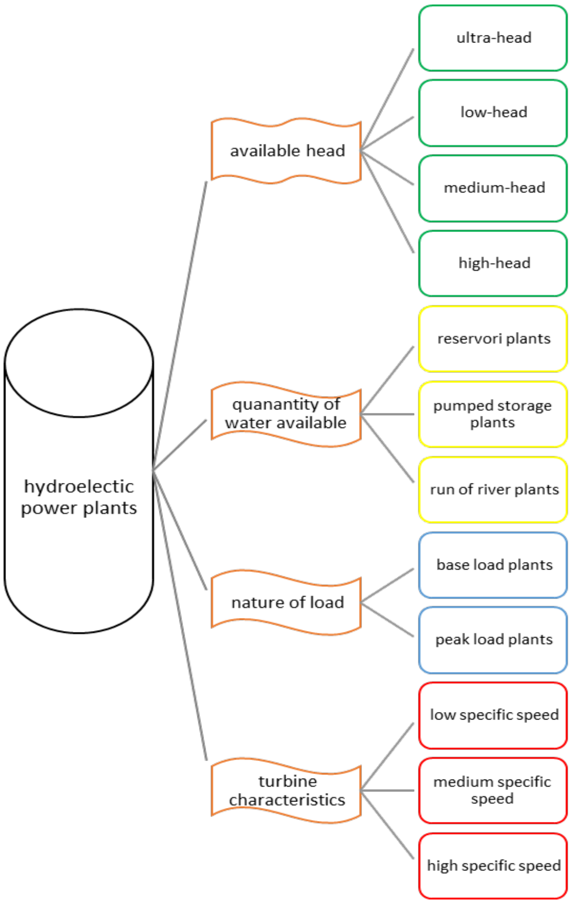

Figure 1. Classification of hydroelectric power plants.

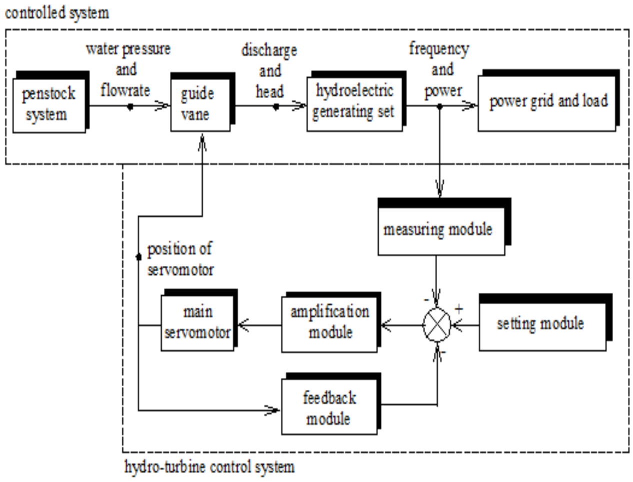

Figure 2. A blocked diagram of hydraulic turbine regulating system.

5. ROUND-ROBIN SCHEDULING ALGORITHM

In different time constants, the whole system consists of T_r, T_a, and T_y. There are different values for the controller which give three outputs included the rotor speed (ω_r), rotor angle (δ) and armature distance voltage ($\acute{E}_q$), respectively. To achieve the desired value, the above-mentioned parameters would have values related to that mode per T_r. To achieve the desired range, the proposed round-robin scheduling algorithm has been used as shown in Fig. 3.

At each algorithm set, the controller was implemented and compared with the initial favorable values. If obtained values are not within the acceptable ranges, it referrers to the decisions block, and based on the previous values, the coefficients were linearly declined or increased. This is done by determining ratios between the observed and optimal values. Initially, they are compared with the basic desired values in formulas and placed in the decisions block through some changes. The decision-making block compared the output results with optimal values and found the Linear Predicative Coefficient (LPC). Then it results in new values again to the input, and the cycle is repeated. The optimal value cannot be absolutely obtained by LPC. Since the ratio of T_r, T_y and T_a are not a linear value and K_p, K_i and K_d were also the same. Therefore, to achieve a more appropriate amount, the loop should be repeated. The feedback loop operates based on the persistence of previous coefficients which is able to recognize the system overall stop. On the other hand, when the initial desirable amount obtained, the new values will be set as comparison parameters to achieve similar or better values than the previous ones. Then, these values are used in decision-making loops to determine new values according to the improvement processes. This procedure gives the chance to compare more than one value and instead of obtaining only one optimal value for the system, the proper range will reach for the overall system. One of the most important advantages to determine the maximum changeability includes errors and variations of general range in the construction. This is done in such a way that we reach from the best possible spot to the best possible range, and thus, more real results will be available for final structure and implementation of the system.

As it is theoretically possible, the values were examined in large numbers with different precision levels, not practically important, a few methods will be considered to stop the whole system. Firstly, if the algorithm reaches exactly the same values after several iterations, the system will not have the ability to improve. Then, the algorithm does not need to be continued. Also, if the differences between these quantities were highly close together with acceptable accuracy and do not, in fact, create a difference in the system reality, then, the system would not need to be continued as well. For example, assume that a value equal to 0.25 is achieved for the Kp factor in one of the loops. Then, the value changes as 0.001in the next loop and becomes equal to 0.251. Then, in the next loop, the value returns to the same 0.25, and the process continues as follows:

K_p = 0.25, 0.251, 0.248, 0.249, 0.251, 0.252, 0.25, 0.249

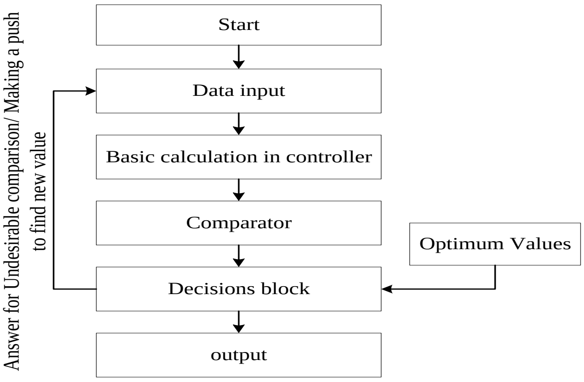

Figure 3. The block diagram of proposed Round-robin scheduling algorithm.

It can be seen that no significant changes would be achieved in the system. On the other hand, the changes are very small in practice, obtaining such precision in variations will be impossible or very difficult and costly, which is not required in such a system. Therefore, if we encounter such values after several iterations, the loop will stop.

Another way is to examine the number of occurrences in the system. If the changes rate follows a workflow process, however, the values are different, so, there is no need to continue the system. Since, after several loops, the values will be repeated. Then, if the loop reaches to such values, it will be stopped after several repeats and would reveal the changes. However, we did not encounter such values in this system. But, it was applied as a condition for stopping the system. For example, the same coefficient K_p:

K_p = 0.25, 0.36, 0.48, 1.01, 2.56, 0.21, 0.37, 0.51, 0.96, 2.31, 0.24, 0.41, 0.5

As it is clear, values are in circulation and the changes would not be in such a way to become convergent to a certain value. Therefore, there is no need to continue this case, and the best states will be considered in the same range as suitable and favorable levels of system error, i.e., the input-output difference, to stop the system and examine other input parameters. After stopping the decision-making, the percentage of means errors were calculated, and better mean percentage considered as the output. The advantage of this system was the ability to find all desired parameters simultaneously. This means there will not be just one parameter considered as an appropriate value in the output, but at the same time, all parameters should be acceptable. For example, if a value leads to obtaining the desired speed, but a very bad slip also occurs, this mode will not be considered as an appropriate mode, and all parameters should be suitable.

In this paper, simulations have been evaluated at different time constants. The results obtained from this method were the results of Round-robin scheduling algorithm and compared with the PID controller results. The results considered as the range of coefficients for the PID controller, and the graphical results of different parameters are based on these factors. In fact, the Round-robin scheduling algorithm is a combination of a genetic algorithm and a neural network. the genetic algorithm leads to new median values to optimal values by comparing. The neural network is obtained based on feedback from previous steps and examines the system values one by one, which leads to an increased number of data. Thus a considerable accuracy will achieve. Due to time-consuming and excessive increase data, there is no need for full implementation of the algorithm. For this purpose, the Round-robin scheduling algorithm has been used because of its certain constraints, lead to a decreased number of unwanted data. In contrast, a disadvantage of this method was its main use which occurs before the implementation of the real system and did not use during the performance of the real system. That is why it used as the basic design to obtain the controller with appropriate coefficients to set up and implement the core system. Another important difference between the proposed method and the above-mentioned methods is that the data is not given to the algorithm sporadically or without formula. In fact, there is a general awareness of how to promote the system. Therefore, this method is merely used to find the input data as well as suitable and more optimized design but is not used to obtain systemic functions.

6. SIMULATION RESULTS

Tables 1, 2 and 3 represented the numerical outcomes within the reasonable ranges for different amounts of Tr. Tables 1 and 2 are related to the values of controller parameters based on their own Tr, in which, the difference from the average value was shown as a percentage. These values represent the acceptable range in the studied time constant.

Table 1. Numeric values for T_r =0.6.

Parameter	Value
K_p	0.25786 ± 2 %
K_i	1.03833 ± 3.5 %
K_d	5.43366 ± 2 %

Table 2. Numeric values for T_r =1.7.

Parameter	Value
K_p	5.15034 ± 2.5 %
K_i	0.28472 ± 3.5 %
K_d	8.43124 ± 2 %

In Table 3, the values have been generally evaluated which had desired results in those scopes. In other words, each of the Tr values can be selected in this range, and the values of controller parameters have changes in the shown ranges.

Table 3. The most optimal numerical range for PID controller parameters for the period of T_r.

Parameter	Value
Best of T_r	0/60~1/95
Error = $\|\omega_{rd} - \omega_r\|$	≤ 0/0085
K_p	0.00100~18.67021
K_i	0.01001~6.42001
K_d	0.00000~9.24640

Figs. 4 and 5 show the transient results of the system that have been achieved by applying the controller without implementing the algorithm. Figs. 4, 5 and 6 are all related to the scheduling of ω_r based on time. As can be seen, about t = 50 is needed so that the system finds an appropriate mode to achieve sustainability. However, Fig. 5 has a far more favourable situation.

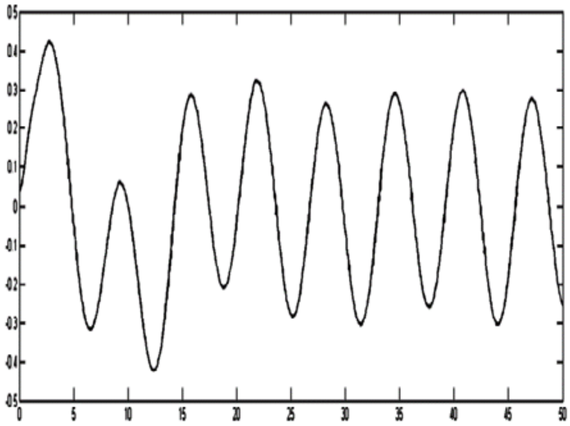

Figure 4. Transient numerical results without algorithms in terms of time and ω_r in the time constant of T_r =0.6.

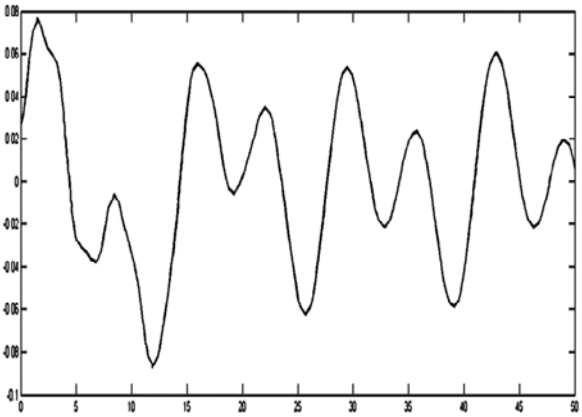

Figure 5. Transient numerical results without algorithms in terms of time and ω_r in the time constant of T_r =1.7.

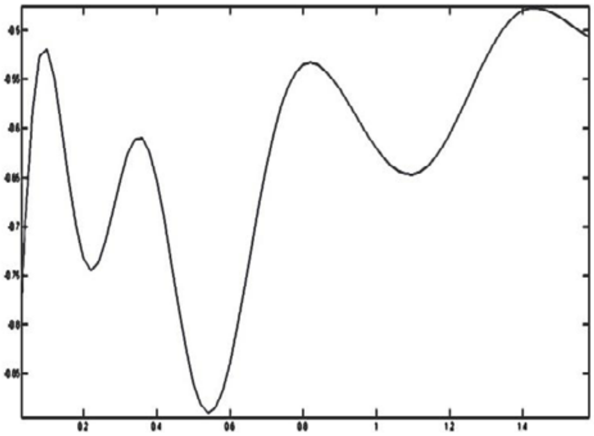

Figure 6. Numerical simulation results in terms of time and ω_r at time constants of T_r =0.6~0.8.

This has not been possible in methods presented in [24], and partly imposed on the system. In fact, this algorithm improve the existing modes and has the ability to achieve the desired values as well. This is one of the most important differences between this algorithm and other methods without the algorithm. In this case, it will be possible to be partially aware of values imposed by the system and put them in a range to deliver the best results. In other words, one can say that it will create a relative control over imposed parameters. Figure 6 shows the function output after applying the algorithm. These values were obtained based on the $T_r = 0.6 \sim 0.8$, which had a good sustainability speed and fewer errors.

But, in Fig. 7, it can be seen that the rate has dropped to about t = 5, and consequently, we will have a faster system. In general, it can be found that in depicted figures the ω_r value has approached the intended value with acceptable speed and is completely controllable.

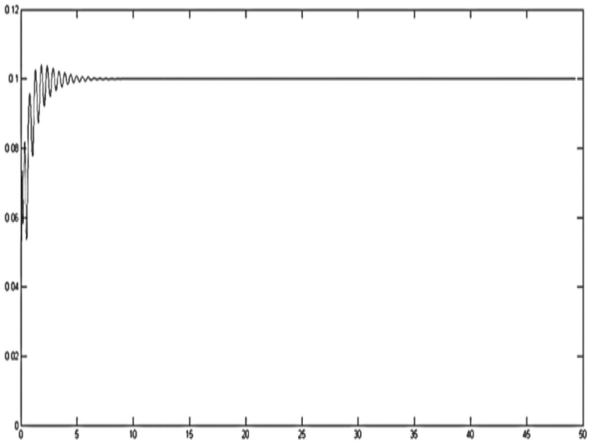

Figure 7. One of the appropriate system responses in the Round-robin scheduling algorithm with coefficients (k_p= 0.25786, k_i= 1.03833, k_d= 5.43366).

7. CONCLUSIONS

In this paper, the Round-robin scheduling algorithm being used to damping of oscillations and oscillatory instability by changing different conditions of the performance. This algorithm improved existing states and was able to reach the desired values. For a certain time constant, the system has the ability to achieve desired controlling factor. At the same time, appropriate inputs range of the turbine system can be determined to prevent generator oscillations error. Another important result of the method is the ability to obtain the allowed tolerance to build a real hydraulic system. This tolerance helps us to reach the precision level of manufacturing as well. A consequence of this is the ability to reduce turbines manufacturing costs without reducing their capability. Finally, the most important advantage of this algorithm was the ability to check several parameters in the input and also other parameters simultaneously in the output.

8. ACKNOWLEDGEMENT

The authors would like to thank the journal editor and anonymous referees for their valuable comments and suggestions which effectively improved the quality of this paper. This research work was supported by Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

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