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Objective functions modification of GA optimized PID controller for brushed DC motor

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ABSTRACT

PID Optimization by Genetic Algorithm or any intelligent optimization method is widely being used recently. The main issue is to select a suitable objective function based on error criteria. Original error criteria that is widely being used such as ITAE, ISE, ITSE and IAE is insufficient in enhancing some of the performance parameter. Parameter such as settling time, rise time, percentage of overshoot, and steady state error is included in the objective function. Weightage is added into these parameters based on users' performance requirement. Based on the results, modified error criteria show improvement in all performance parameter after being modified. All of the error criteria produce 0% overshoot, 29.51%-39.44% shorter rise time, 21.11%-42.98% better settling time, 10% to 53.76% reduction in steady state error. The performance of modified objective function in minimizing the error signal is reduced. It can be concluded that modification of objective function by adding performance parameter into consideration could improve the performance of rise time, settling time, overshoot percentage, and steady state error.

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1. INTRODUCTION

The main objective of this paper is to evaluate the performance of modified error criteria selected as objective function in optimizing the value of K_P, K_I, and K_D for velocity control PID controller by using Genetic Algorithm for brushed DC motor. The effect of adding four PID performance parameters that is overshoot percentage, steady state error, settling time and rise time into objective function equation is analyzed by using Genetic Algorithm optimization. DC motor is widely being used in industry due to its low cost, facileness to control, good braking. and good speed regulation performance [1-4].

Genetic Algorithm is widely being used as an optimizer such as in project planning [5], exergoeconomic optimization for geothermal power plant [6], and PID optimization [7]. There is a lot of control method such as conventional PID controller, LQR controller [8], neural network controller [9], fuzzy controller [10-12]. Recently there is a lot of intelligent optimization method such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO),Artificial Bee colony, Firefly Algorithm, and Bacterial Foraging (BF) [7, 13-23].

Authors in [15] optimized the PID controller by using PSO and compare the results with GA and Ziegler-Nichols. From the results PSO eliminates the overshoot, while GA and Ziegler-Nichols produced some overshoot. In terms of settling time, PSO is the best followed by GA and Ziegler-Nichols. The difference of settling time between GA and Ziegler-Nichols is not significant. It could be seen that Ziegler-Nichols have better rise time than GA and PSO [15]. The PSO could not surpass Ziegler-Nichols in terms of rise time due to the PSO optimization that only consider error function to optimize the PID. By adding rise time component into error criteria, the PID performance could have improve in rise time performance.

Authors in [17] used Genetic Algorithm to compare the performance of original error criteria, Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute magnitude of the Error (IAE), Integral of the Squared Error (ISE), and Integral of Time multiplied by the Squared Error (ITSE) to tune PID controller to compensate the effect of time delay in the system. It is clear that by using GA that the percentage of overshoot is smaller compared with Ziegler-Nichols and iterative method but by using original error criteria the percentage of overshoot is still present. The settling time obtained by using original error criteria (GA) does not have significant difference compared with Ziegler-Nichols and Iterative Method. It could be seen that the rise time of Ziegler-Nichols is better than optimization by using GA-original error criteria [17]. Therefore, based on authors' work, the GA optimization could not perform better in terms of rise time and yield small improvement in settling time compare with Ziegler-Nichols method which is only a classical tuning method. The original error criteria that only focusing on minimizing the error without considering settling time and rise time component is the reason for slower rise time and insignificant improvement in settling time.

Based on works in [15] and [17] works that produce worse rise time and insignificant settling time improvement when optimizing PID by using GA compare with Ziegler-Nichols, therefore this paper intend to add settling time, rise time component into original error criteria formulas that only consider function of error when optimizing the gains value. Therefore, based on the related works above author intended to add overshoot percentage, steady state error, settling time, and rise time component into the error criteria such as ITAE, IAE, ISE, and ITSE to be optimized by using GA. GA optimization by using original objective functions only consider minimizing function of error, when iterating the optimal gains values. Besides integrating the error function only, performance parameter such as overshoot percentage, O_v, steady state error, SS_e , rise time, t_r, and settling time, t_s, is added with the original objective functions to ensure that optimization process also include other performance indicators as criteria to produce optimum results. Based on the modification, the performance for all of error criteria shows improvement in eliminating the overshoot percentage to 0%, reducing the rise time by 29.51%-39.44%, decreasing the settling time by 21.11%-42.98%, and reducing the steady state error by 10%-53.76%. The details analysis is evaluated as in the results and discussion.

2. RESEARCH METHOD

2.1. Brushed DC motor

The system of brushed DC motor modeled PPSM63-L01 manufactured by Shanghai Dixi Technical Co. Ltd is identified. The bump test was conducted in order to determine the systems of the motor based on the velocity as the output and the voltage as the input. The final form of the transfer function that of the brushed dc motor is as in (1) follow:

$$G(s) = \frac{104.9}{s^2 + 103.5s + 2617} \tag{1}$$

2.2. PID tuned by genetic algorithm

Previously in [24], authors compared the Genetic Algorithm tuning of PID with Ziegler Nichols and Skogestad IMC. Author had previously compared the modified ITAE function with classical design formulas. In this paper author intended to evaluate in details the effect of modification on ITAE, ISE, IAE and ITSE error criterion. The objective function based on four different error criteria that is being used in GA optimization of PID controller can be described in (6-9) below.

$$ITAE = \int_0^{\tau} t\,|\,e(t)\,|\,dt \tag{2}$$

$$IAE = \int_0^{\tau} |\,e(t)\,|\,dt \tag{3}$$

$$ISE = \int_0^{\tau} e(t)^2 dt \tag{4}$$

$$ITSE = \int_0^{\tau} te(t)^2 \, dt \tag{5}$$

$$ITAE_{Modified} = \int_0^{\tau} t \,|\, e(t) \,|\, dt + \alpha O_v + \beta SS_e + \delta t_s + \gamma t_r \tag{6}$$

$$IAE_{Modified} = \int_0^{\tau} |\, e(t) \,|\, dt + \alpha O_v + \beta SS_e + \delta t_s + \gamma t_r \tag{7}$$

$$ISE_{Modified} = \int_0^{\tau} e(t)^2 dt + \alpha O_v + \beta SS_e + \delta t_s + \gamma t_r \tag{8}$$

$$ITSE_{Modified} = \int_0^{\tau} te(t)^2 \, dt + \alpha O_v + \beta SS_e + \delta t_s + \gamma t_r \tag{9}$$

where e(t) is error signal, O_v is overshoot percentage, SS_e is steady state error, t_s is settling time, and t_r is rise time. α, β, δ, and γ indicate weightage for each performance parameter. Weightage is assigned for each parameter. User could defined the weightage based on their design requirement or priorities. Based on observation, by using weightage of α=1.5, β=15, δ=7, and γ=1, the plant as in (1) achieve desirable performance. The total value of right hand side of each equation in (2-9) is defined as objective function value.

After modifying as in (6-9), small value of the objective function could not be used as an indicator to evaluate the performance of the objective function as the objective function have additional work in considering the error signal is small simultaneously with considering others performance parameters. The modified objective function did not work solely on integrating the error signal, e(t) only but also considering the performance parameters. In this case the objective function value is evaluated by applying the fix value of PID gains into the objective function. K_P, K_I, and K_D values used is 549.44, 7.8925×10^3, and 4.0679 respectively. The gain values is obtained from ITSE modified objective function. Fix value is used so that the comparison of the output objective function value could be done fairly as the fixed variable is K_P, K_I, and K_D.

The main objective of the GA is to optimized the value of K_P, K_I, and K_D based on the objective function assigned. The block diagram of PID tuned by GA is shown in Figure 1. The general process of genetic algorithm process is represented in Figure 2. The process of genetic algorithm to tune the PID gain can be described as follow:
- K_p, K_I, and K_D is set as the unknown parameter to be optimized by GA. The initial population is set up to 50. The population type used is double vector as the problem involved mixed integer value. The lower bound and upper bound of the output is set as [0 0 0] and [700 8000 5] respectively.
- The population is evaluated whether it fulfills the stopping criteria.
- If the stopping criteria is not fulfilled, the parent is selected based on the fitness of the chromosomes. The elite count created in this simulation is 0.1
- New children is created by using crossover and mutation. Crossover Fraction is set to 0.8. The mutation function used is based on the constrain condition. For constrained condition the algorithm randomly generate directions influenced by the previous generation. For unconstrained problem, the algorithm add random number to vector entry of an individual based on Gaussian distribution.
- Process 1 to 4 is repeated until stopping criteria is fulfilled. The stopping criteria is based on the average change of objective function values. If the average change of objective function values is less than objective function tolerance, 0.000001 for at least 50 latest generation, the GA is terminated. In a condition where the stopping criteria is not achieved, GA proceed until it reached maximum 300 generations.
- Simulation is repeated for 20 times to obtained the standard deviation of objective function value to observe the consistency of data. K_p, K_I, and K_D that have the smallest value of objective function is selected to represent the error criteria.

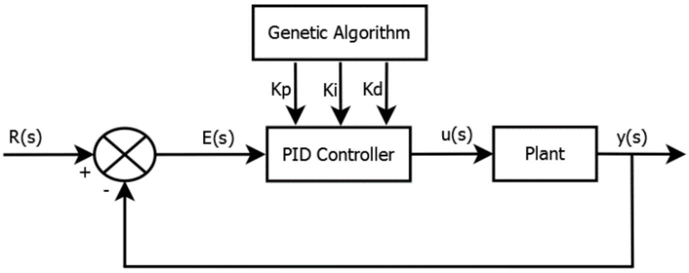

Figure 1. Block diagram of PID tuned by GA [24]

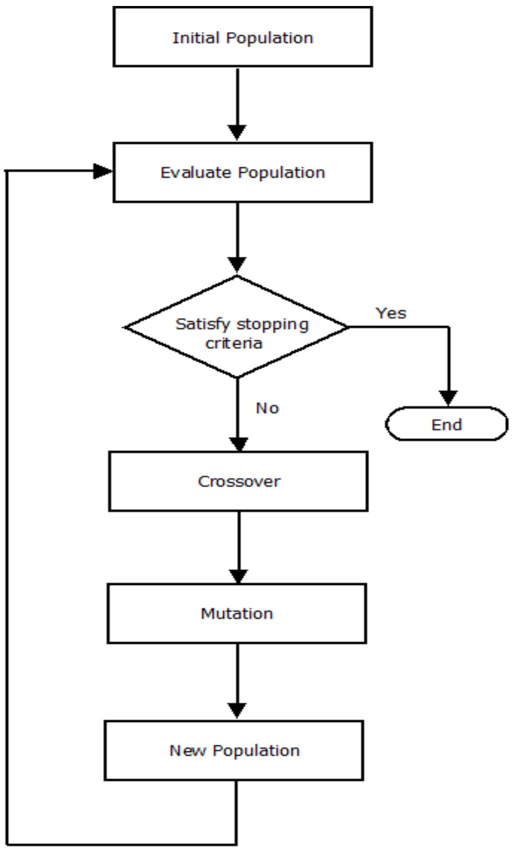

Figure 2. General process of genetic algorithm [24]

3. RESULTS AND ANALYSIS

Based on the results obtained from the simulation, it could be seen that the performance in terms of rise time, settling time, overshoot percentage and steady state error are improved significantly. The value of gains is tabulated in Tables 1 and 2. The modified objective function yields bigger value of proportional and derivative gain while the integral gain changes are not significant. The results show clearly that the objective function value increased after the objective function is modified. As stated in methodology, the original objective function aims is to minimize the error signal, but after being modified a small value did not indicates that the objective function have the best performances as there is additional component in the equation.

Table 1. K_P, K_I, and K_D values of original objective functions optimized by GA

Gain	Original Objective Function			
	ITAE	IAE	ISE	ITSE
K_P	314.13	317.42	389.66	353.49
K_I	7954.8	7972.1	7938.5	7999.8
K_D	2.7802	3.0011	2.9074	3.02

Table 2. K_P, K_I, and K_D values of modified objective functions optimized by GA

Gain	Modified Objective Function			
	ITAE	IAE	ISE	ITSE
K_P	549.4445	565.29	574.7	562.201
K_I	7892.5	7886	7703.6	7961.8
K_D	4.6079	4.7364	4.7968	4.7182

Tables 3 and 4 shows the objective function value by using modified ITSE gain input. The gain values need to be fixed in order to make a fair comparison between the objective function. Based on the value of objective function in Tables 3 and 4, performance of GA could be evaluated. By using original objective functions, the cost/objective function value have smaller value than modified objective functions. This show that GA performed better by using original objective functions compare with modified objective functions in minimizing the error. However, in evaluating PID performance, four performance indicator that are rise time, settling time, steady state error, and overshoot percentage is more important because it influence the hardware performance. Based on the tabulation of the output performances in Tables 5, 6, 7, and 8, the response performance of modified objective functions improve significantly compared with original objective functions. The original objective function that focused solely on minimizing the error is the cause of the small value in the objective function. After being modified, others performance parameters is taken into consideration in iterating the value of gains indicates the reason of bigger value of objective function.

It can be concluded that ITSE have the best ability to minimize the error signal before and after being modified. The modification improve the ISE function and produce better value than ITAE function compared with before modification. Compare with previous work in [24] the original ITAE produce slower settling time with the presence of overshoot. The additional of overshoot and steady state error component into ITAE objective function eliminates overshoot percentage and reduce settling time, however modified ITAE function still produced slower rise time compared with original ITAE. The addition of rise time and settling time component as in (6-9) yields faster rise time compare with previous work in [25]. As in subtopics 3.41, for ITAE the rise time performance improve by 39.44%. The improvement in this parameter also could be seen in other modified error criteria.

Based on Table 1 and Table 2, the different value of K_P, K_I , and K_D produced before and after the modification of objective functions yields different output step response. Proportional gain, K_P is basically directly proportional to error function. Integral gain, K_I is associated with reducing the steady state error. The derivatives terms work based on the rate of change of error signal of the systems [25]. K_P for ITAE, IAE, ISE, and ITSE increase by 74.9%,78.09%, 47.49%, and 59.04% respectively. The increment in proportional gains caused the system that is optimized by using modified objective functions improve the response time of the system to reach the set point value. K_D increment reduce the rise time of the systems. K_I for ITAE, IAE, ISE, and ITSE before and after modification shows slightly decrement in values. The difference is by 0.79%, 1.08%, 2.96%, and 0.48% for ITAE, IAE, ISE, and ITSE respectively.

Therefore the changes of K_I values before and after the modification could not justify the decrement in steady state error as shown in Tables 5, 6, 7, 8 as the changes in K_I values are insignificant. Thus it could be concluded that the major increment of K_P is the main reason for the decrement in steady state error as gain component is proportional to error function. K_D values for ITAE, IAE, ISE, and ITSE shows huge increment by 65.73%, 57.82%, 64.99%, and 56.23% after all of the error criteria were being modified. The significant increment of KD values justified the reduction of overshoot percentage and reduction in settling time after the objective functions are modified.The details analysis for each error criteria performance based on the predefined performance indicators is discussed in subsection 3.1, 3.2, 3.3, and 3.4 below.

Table 3. Objective function values of original objective functions optimized by GA

	Original Objective Function			
	ITAE	IAE	ISE	ITSE
Objective Function Value	1.0163×10^{-4}	0.0112	0.010	5.8442×10^{-7}

Table 4. Objective function values of modified objective functions optimized by GA

	Modified Objective Function			
	ITAE	IAE	ISE	ITSE
Objective Function Value	6.7020	6.7131	0.0764	0.0664

Table 5. Performance of original and modified ITAE

Performance Parameter	Original ITAE	Modified ITAE	Improvement
Rise Time (s)	0.0071	0.0043	39.44%
Settling Time (s)	0.0115	0.0071	38.26%
Overshoot (%)	0.4822	0	100%
Steady State Error	0.0047	0.0041	12.77%
Standard Deviation of Objective Function Values	4.99×10^{-6}	1.707	-

Table 6. Performance of original and modified IAE

Performance Parameter	Original IAE	Modified IAE	Improvement
Rise Time (s)	0.0069	0.0042	39.13%
Settling Time (s)	0.0121	0.0069	42.98%
Overshoot (%)	0	0	0%
Steady State Error	0.0043	0.0022	48.84%
Standard Deviation of Objective Function Values	1.218×10^{-4}	2.623	-

Table 7. Performance of original and modified ISE

Performance Parameter	Original ISE	Modified ISE	Improvement
Rise Time (s)	0.0061	0.0043	29.51%
Settling Time (s)	0.009	0.0071	21.11%
Overshoot (%)	1.6644	0	100%
Steady State Error	0.0093	0.0043	53.76%
Standard Deviation of Objective Function Values	9.34×10^{-6}	0.0243	-

Table 8. Performance of original and modified ITSE

Performance Parameter	Original ITSE	Modified ITSE	Improvement
Rise Time (s)	0.0064	0.0042	34.38%
Settling Time (s)	0.0103	0.0069	33.00%
Overshoot (%)	0.3827	0	100%
Steady State Error	0.002	0.0018	10%
Standard Deviation of Objective Function Values	6.48×10^{-8}	0.024	

3.1. Effect of modification on ITAE

Based on Table 5, modified ITAE have 39.44% and 38.26% better rise time and settling time respectively. Based on Tables 1 and 2, the increment of KP value from 314.13 to 594.4445 is the reason behind the reduction The percentage of overshoot is reduced to 0. The steady state error reduce by 12.77%. By modifying the ITAE function, the performance improves the most in terms of settling time. The standard deviation value of original ITAE is 4.99e-06, significantly smaller than modified ITAE, 1.707 indicates the inconsistency of data obtained from modified ITAE compared with original ITAE.

3.2. Effect of modification on IAE

In Table 6, modified IAE shows improvement of 39.13% and 42.98% for rise time and settling time respectively. The overshoot percentage is at the best before it modified, therefore the modification does not have any effect on this sector. The steady state error is reduced by 48.84%. The effect of modification have the most impact on settling time performance.

3.3. Effect of modification on ISE

Original ISE yields the biggest overshoot percentage among all performance indices,1.6644%, after being modified the overshoot percentage become zero, this is due to the overshoot component is been taken into consideration when GA iterates the value of gains. The rise time reduced by 29.51% while settling time have reduced by 21.11%. The steady state error have reduction by 53.76%. The modification of ISE function improved overshoot component the most compared with other performance parameters. As in Table 7, the standard deviation become bigger due to the effect of modification effect the decision of GA to meet the stopping criteria because of the consideration for others performance parameter instead of the integral of error signal only.

3.4. Effect of modification on ITSE

Based on the comparison in paragraph 5 in results and discussion section, it can be seen that the performance of ITSE is the best at minimizing the error signal. The standard deviation of ITSE data is also the best compared with ITAE, IAE and ISE function. Based on Table 8, in terms of rise time and settling time, ITSE improved by 34.38% and 33.00% respectively after being modified. The overshoot percentage reduce from 0.3827% to 0%. The steady state error produced is reduced by 10%. It can be concluded that ITSE function have the biggest improvement in terms of rise time after being modified.

4. CONCLUSION

The effect of modification on error criteria as objective function in tuning the PID controller by using GA is evaluated. Performance parameter such as overshoot percentage, steady state error, rise time, and settling time is added into error criteria. The modification of the objective function seems to eliminate the overshoot percentage, reduce steady state error, settling time and rise time. The objective function value is increased after the objective function is being modified as the objective function considered the performance parameter to be optimized despite of minimizing the error signal only as in original objective function. In conclusion, overall performance of the systems could be improved by modifying the objective function as in (6-9).

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