

## A response time reduction for DC motor controller using SISO technique

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### ABSTRACT

In an industrial controller, over five decades there are many attempts had been proposed to improve a method of tuning proportional gains of PID controller. Where in the review there is a very little attention have been paid to use satisfactory tuning to get maximum performance. This paper proposes an alternative solution to maximize optimization for a controller-based DC motor. The novel methodology relies on merge proper tuning with optimization using SISO-Optimization technique-based tune (*SISO<sub>OBT</sub>*). The comparative study has been done by utilizing classical tuning methods Z N, SIMC, CHR, and AMIGO, to obtain suitable tuning to be joined with (*SISO<sub>OBT</sub>*). The proposed PID controller was examined in term of response time characteristics. This strategy provides a superior reduction in peak overshoot Pos, dead time  $t_d$ , rise time  $t_r$ , settling time  $t_s$ , and peak time  $t_p$ , that could be utilized to improve the responses of a DC motor controller. Based on comparison results, it was founded that a CHR based SISO\_optimization (*CHR<sub>OBT</sub>*) playing a superior role over others in term of Pos 0%,  $t_d$  0.1811  $\mu$ sec.,  $t_r$  17.2  $\mu$ sec,  $t_s$  30.7  $\mu$ sec,  $t_p$  80  $\mu$ sec, and the number of iterations iter No 9. Ultimately, this work overcome the majority of previous work that related with this approach.

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## 1. INTRODUCTION

Over seven decades, Proportional Integral Derivative PID algorithm is one of the widely utilized in industries for controlling feedback systems closed loop controller, in case of simplicity and ability to meet requirements of controller systems to be used in a wide scope of plant models [1]. It became a standard tool and found in all areas, where more than eleven thousand controllers in the refining, chemicals, and pulp and paper industries demonstrated that more than 97% of regulatory controllers had in PID algorithm [2]. The basic function of the PID is to decrease the divergence between the process variable and the setpoint. It is possible to obtain the modification gains to get two wishes: fast responses with better stability by tunes properly the inputs, to overcome the problem's plant, such as time delays and nonlinearities in a higher-order system. Practically, these two desires cannot be accomplished together [3].

PID controller stands for three proportional gains  $G_i$ : proportional, integral and derivative  $K_p$ ,  $K_i$  and  $K_d$ . The  $K_p$  is directly proportional to the measured error when gain increased steady-state error is reduced but the affinity of oscillation in system increases. The second term integral gain  $K_i$ , while increases the steady-state error is gone to disappear but peak overshoot raises. The third term used to improve the

stability of the system by reduction PoS and  $t_s$ . Consequently, fine adjusting these proportional gains, PID controller can obtain fashioned control action to a response time of plant system [4, 5].

Despite, PID controller has just three adjustable gains, but it is very difficult to find contributed PID gains to meet desired modifications in response time, however the leakage in modification caused poorly tuned and increase time-consuming for improving controller settings. To enhance the performance of the controller it should be used systematic tuning method, otherwise, it is poorly tuned and raise the consumed time through process tests. The significant issue in PID controller is how to tune proportional gains sufficiently [6]. Theoretically, PID can be defined in s-domain and z-domain to modify the time domain characteristics. The system's response might be estimated by  $t_d$ ,  $t_r$ ,  $t_s$ ,  $P_{os}$  and steady-state error (Ess). [7].

More than five decades, enormous tuning techniques have been suggested to acquire acceptable response time characteristic ( $t_r$ ,  $t_s$ ,  $P_{os}$ , Ess). A portion of these tuning techniques has considered just a single of these objectives as a criterion for their tuning algorithm, while others considering more than one of these criteria. Essentially, tuning controller techniques are sorted under transient response into two fundamental sorts; open loop and closed loop methods. The open loop tuning method allude to techniques that tune the controller when it is in manual state and the plant operates in open loop. Where, closed loop tuning methods refer to techniques that tune the controller during an automatic state in which the plant is known to process and operating in a closed loop. Based on a survey, the early published focuses on classical methods, for instance, the Ziegler–Nichols Z-N oscillation and reaction curve method, Cohen Coon curve method, and Chien-Hrones-Reswch CHR method. These methods are widely utilized in cases of easy to use with simplicity calculation. They rely on phase and gain margin specification. In contrast, the enormous numbers of the various process plant will usually cause poorly tuned proportional gains. It has been seen that PID controller tuning is very troublesome by traditional methods utilizing graphs and mathematical analysis [8, 9].

By contrast, despite the classical tuning methods are as yet utilized extensively in the industry, however they are insufficient for performance processes and often unable to obtain optimal system responses, further require extra modifications, restricted accuracy, particularly in dynamic systems, other than don't perform fully for multiple specification design issues. These impediments originate from two reasons: firstly, these techniques use lacking procedure data and performance which leads closed-loop systems to poor damping. Likewise, the performance of the controller is influenced specifically by changes in process dynamics because of nonlinearities and variation parameters. Obviously, conventional tuning methods are not perfect for improving response time with overshoot [10, 11]. Experimentally, it is very hard to design controller based unstable plant models compared with stable models, in case of settling time and overshoot are relatively larger for unstable systems than that of stable systems. Significantly, the difficulty raises if there exists a time delay in the unstable process. For this reason, the developed tuning formulas are complex and not practical purposes for unstable models. The better tuning algorithm should be had an enhanced procedure to do the following objectives: 1) the tuning rules should be analytical, suitable motivation, and preferable tuning model; 2) more simplicity and convenience to memorize; 3) must suitably employ on a wide range of processes [5, 12, 13].

Some tuning techniques are superior to others for widely used in the controller applications, each method has its benefits and drawbacks. A few analysts concentrated on their drawbacks to enhance tuning methods, in case of rising complexities and consume the time of implementation. Therefore, using just tuning methods to adjust proportional gains is not sufficient to improve PID controller. On the other side, Evolutionary algorithms (EA) have been used over thirty years to find a solution for complex single and multi-objective optimization problems, for instance, Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) [14-16]. The robustness of optimization algorithms can be characterized into two concepts. The first concept relies on  $T_i$  parameter,  $P_{os}$  and number of iterations Iter No., where a second concept depends on the performance of an algorithm under the suitability to improve the system [17, 18].

Classical optimization methods are relying upon presumptions for instance convexity of the cost function, differentiability, and constraints that must be fulfilled. To diminish the complexity of tuning controller parameters, constrained optimization must be fulfilled by pursued efficient presumptions to optimize results after every iteration [19]. GA has been invented through the 70s of last century, which relay on parallel search techniques to adjust PID gain precisely, but it suffers in enormous computational through optimizing parameter's controller, leads to decrease the speed of the system through premature convergence and convergence [20]. A few computational tuning algorithms frequently used these days, for instance, Internal Model Control (IMC), which uses to reduce the error by predicting the output, besides adjusting the controller gain to achieved desired closed loop response with sophisticated overshoot. Substantially, this method is based on finding the parameters of the overall transfer function in some transformed domain to have a desired set-point response [21].

The overview indicates moderately lesser work on the comparative study for different tuning methods. Controller design methods for unstable systems are limited and this research has taken attention in the recent past. Indeed, Interactions between the loops make the design progressively troublesome and it is essential to consider these points through implementing a PID controller. By contrast, there are a few downsides in past works originate from very few analysts focused on taking in thought the better offsetting between overshoot with response time  $t_d$ ,  $t_r$ ,  $t_s$  through tuning gains [22, 23]. Based on a survey, there are enormous tuning techniques have been proposed to enhance the accuracy of a controller, but small attention has been paid in the review to use both sufficient tunings with optimization to minimize reduction of response time. Figure 1 shows the comparison response time between different classical tuning methods, where the aim of this paper is to overcome currently methods.

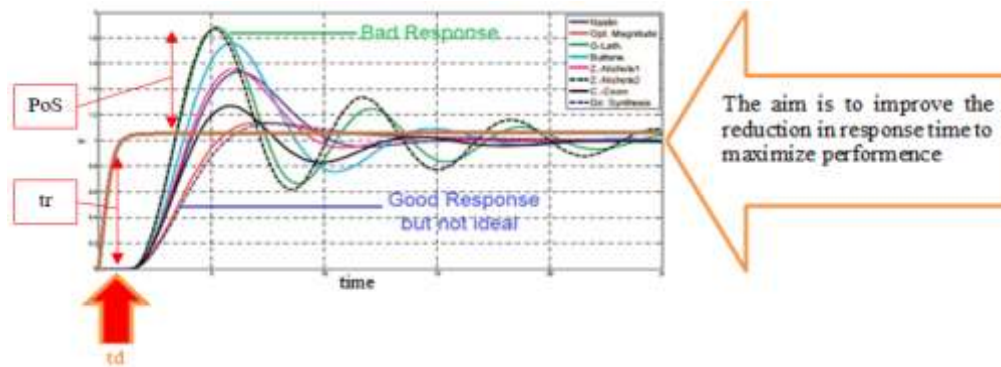


Figure 1. Time responses of PID controller under different classical methods

Considerably, Improving a system has been achieved when taking into consideration a systematic process for adjusting PID gains to increase reduction response as obviously cleared in Figure 2, hence this point is very crucial in field of improving controller systems and there many attempts were done before but not accomplished the highest reduction in time response specification, where this work takes in consideration all past drawbacks in previous works to achieve highest reduction response time reaching to Microsecond unit.

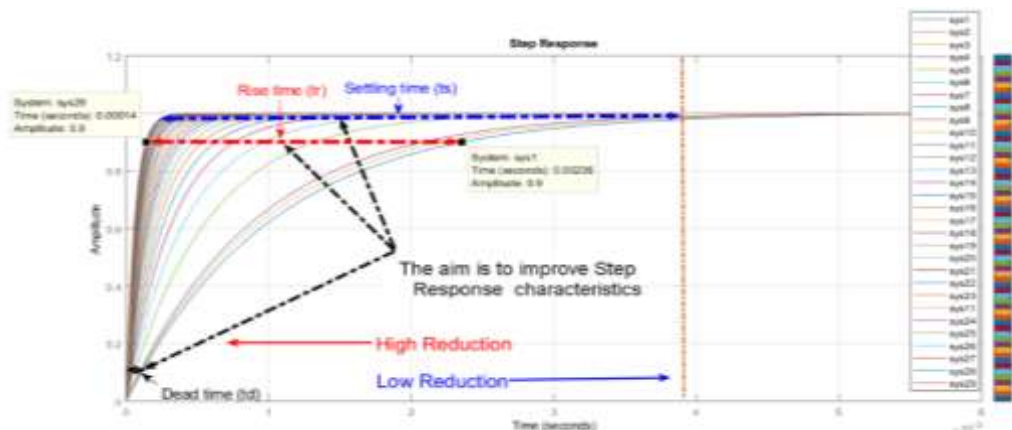


Figure 2. The aim of this work to improve step response significantly

In this research, a novel method was proposed for higher adjusting PID gains to become an alternative solution to reduce response time significantly, by combining proper tuning with SISO technique *SISO<sub>OBT</sub>*. to be employed for designing a DC motor controller. The proposed methodology relies on a comparative study of using four different tuning methods: Ziegler -Nichols method Z-N, Chien-Hrones-Reswick CHR, Skogestad IMC method, and Approximate MIGO method, with a second order system,

prepared to proceed a comparison between them to achieve proper tuning gains to be applied as a better initialization value with SISO technique.

To evaluate the proposed optimization method in term of response time ( $t_d$ ,  $t_r$ ,  $t_s$ ) and Overshoot Pos, it was analyzed the transient response to those tested tuning methods separately and jointly with **SISO<sub>OBT</sub>**. Based on comparison results, CHR based proposed method overcomes other tuning methods for better reduction response time and overshoot. The novelty of this method is to get an optimal reduction in term of  $T_i$  and Pos. This method also can be used to improve the performance of GA for best searching by Modifying Initializing Fitness Function (MIFF). The proposed methodology is organized in the following sections: Research Methodology is presented in Section 2, results and analysis are shown in Section 3, and conclusions follow in Section 4.

## 2. RESEARCH METHOD

To design PID controller accurately, it is very important to find out the mathematical model for the selected DC motor, then applying the proposed methodology as will be explained in subsections 2.1 and 2.2 respectively.

### 2.1. Mathematical Model of Speed DC Motor

From Figure 3, it was derived the mathematical model of DC motor by using SI units. In this model we assume that the motor torque  $K_t$  and back emf  $K_e$  constants are equal, therefore:

$$K_t = K_e = K \quad (1)$$

$$K_i = J \cdot \ddot{\theta} + b \cdot \dot{\theta} \quad (2)$$

$$V - K\dot{\theta} = L \cdot \frac{di}{dt} + Ri \quad (3)$$

Where

$L$  is the electric inductance

$R$  is the resistance of the coil

$b$  is motor viscous friction constant

$\theta$  is the speed of the shaft

$K_t$  motor torque constant

$K_e$  electromotive force constant

$J$  is the moment of inertia of the rotor

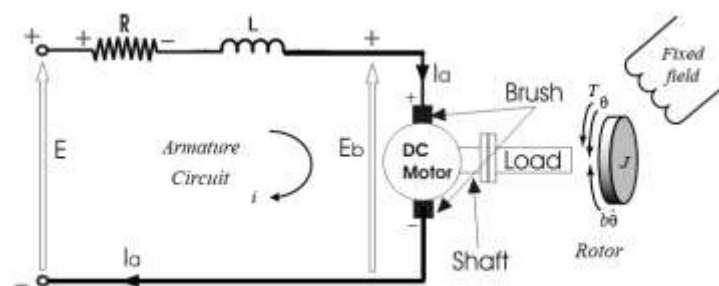


Figure 3. DC motor circuitry

By applying the Laplace transform to get s-domain equations:

$$s(Js + b)(s) = KI(s) \quad (4)$$

$$(Ls + R)Is = V(s) - Ks(s) \quad (5)$$

By eliminating  $I(s)$ , it can be formulated the Mathematical Model of Speed DC-Motor:

$$P(s) = \frac{\dot{\theta}}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \frac{[rad/sec]}{V} \quad (6)$$

By subtracting the following specification values in (6)

$$L = 0.5H, R = 10hm, b = 0.1N.m.s, Kt = 0.01N.\frac{m}{Amp}, Ke = 0.01V.\frac{sec}{rad}, J = 0.01 kg.m^2$$

We have got the speed mathematical model of the selected DC motor under study as in 7:

$$P(s) = \frac{0.01}{0.005 s^2 + 0.06 s + 0.1001} \quad (7)$$

## 2.2. Proposed Design

We proposed a methodology to optimize proportional gains (Kp, Ki, Kd) for PID controller by following two methods. Firstly we used four different classical tuning methods Z-N, SIMC, CHR, and AMIGO which have been widely used in controller manufacturer and mostly studied in control engineering tuning methods, to tune PID controller separately to obtain Ti characteristics and Pos, and to generate compensator transfer function prepared to be used as a modified control system. Secondly, to contribute improving the reduction Ti and Pos for a selected model, the Optimization base Tune (**OBT**) is a suitable solution, where this approach needs for a benchmark comparison to nominate the best tuning method to be joined with SISO technique.

Based on both concepts' suitability of optimization and response parameters, we perform a comparison between tuning under study separately and jointly using SISO optimization based tune (**SISO<sub>OBT</sub>**). All these methods under study are simulated by giving a unit step change in set point. The Ti results based proposed method have been compared with each other tuning methods under study. This is done by the chosen "Design Requirements" based root locus plot set to define the desired characteristics of the step response. The results show that the **SISO<sub>OBT</sub>** technique provides two significant aspects. Firstly, specifying the design requirements will create visual limitations on the graphs to help the user set and find appropriate gains. Secondly, how changes in the transfer function's poles and zeros alter the root locus and bode plots in live response, besides tracking the changes in gain that can influence to system's step response. Figure 4 demonstrates the proposed methodology to optimize PID gains, where the steps of the proposed methodology are explained as follows:

- a) Import the mathematical model into control and estimation tool.
- b) Putting compensator gain to 1 and selecting r to y for negative feedback controller using step response for analysis plot.
- c) From LTI viewer of SISO design, it can be obviously seen Figure 5 that the system is very poor, where the Ti parameters are: td 119.1msec., tr 0.627, ts 1.85sec and tp 3sec and final amplitude 0.09.
- d) Now adding the PID controller to a system and applied Z\_N tune-based step response to extract proportional gains, then updating the compensators gain and transfer function. This is the first stage of adjusting PID gains.
- e) On LTI viewer setting the design requirements to the following; tr 1e-8 for 90%, ts 2e-8, PoS 2.
- f) Based on Z-N tuning, now using optimization SISO closed loop r to y to re-correct the location of compensator Zeros, for fine adjusting PID again. Where this is a second stage regarding proposed methodology.
- g) From LTI viewer extract TI and Pos, it can be observed there is a significant reduction in Ti compared with the first stage.
- h) Now we can extract the final TF of compensator with optimization proportional gains.
- i) Using switching mod algorithm to select one by one different tuning methods SIMC, CHR, AMIGO and repeat those steps 1-8 for each one as shown in Figure 4. This step provides comparison results between tuning under study based proposed methodology to select a suitable tune that could be chosen to finalize the design based proposed methodology (**OBT**).

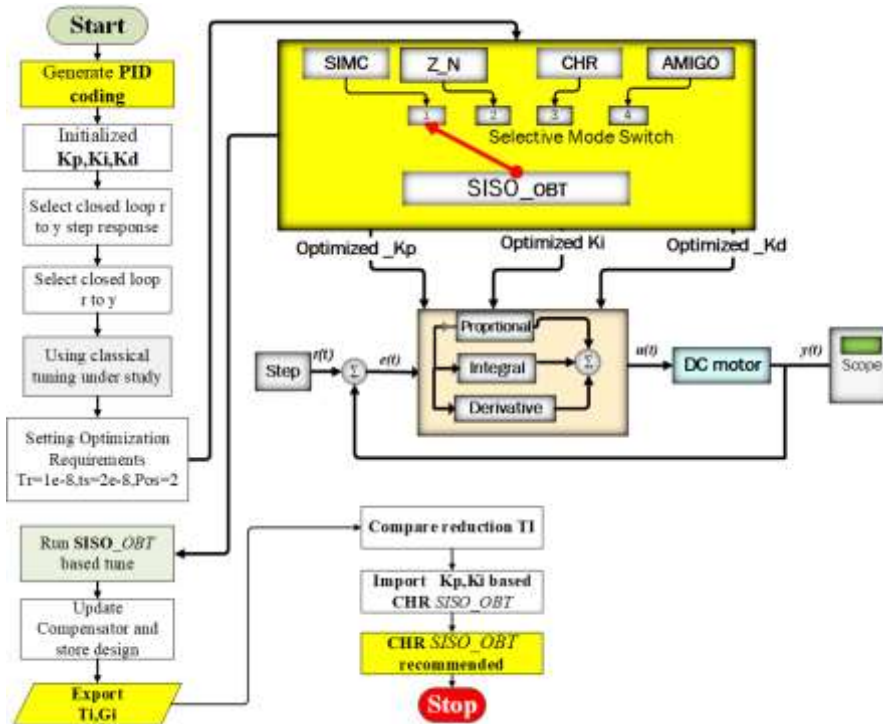


Figure 4. Proposed optimization based tune (*OBT*) for PID controller

### 3. RESULTS AND ANALYSIS

This section presents the simulation results with comprehensive examination discussion. The transient response of the selected plant illustrated in Figure 5, where the step response characteristics are:  $t_d=119.1\text{msec}$ ,  $t_r=1.02\text{sec}$ ,  $t_s=1.85\text{sec}$ ,  $t_p1.85\text{sec}$ , steady-state time  $SSt$  3sec and peak amplitude 0.0907. Based on results, the system is a very slow response.

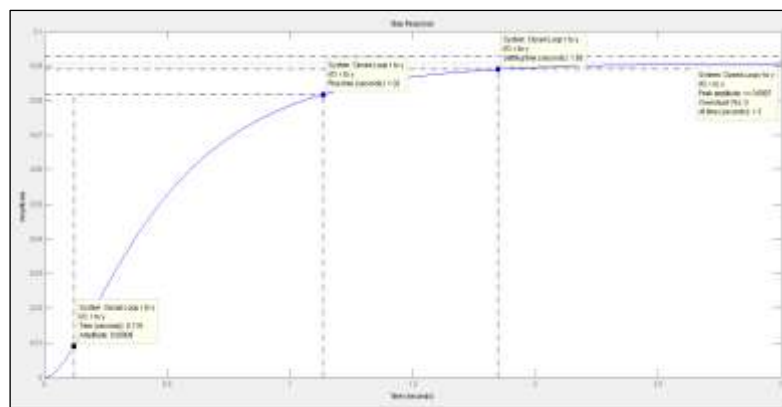


Figure 5. Step response of uncontrolled system

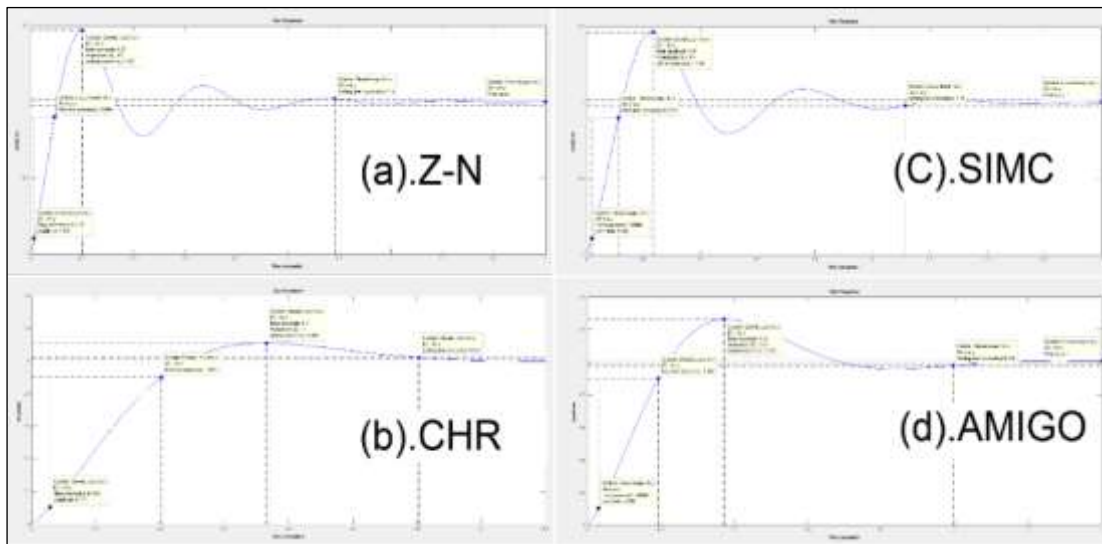
#### 3.1. Analysis based Tune Lonely

The estimation benchmark is based on analyzing  $T_i$ ,  $Pos$ , that was examined under time domain specifications. The simulated system response was gotten based on four different tuning methods Z-N, CHR, SIMC, AMIGO as shown in Figures 6(a-d). From Table 1, it can be seen that there is an improvement in a reduction of response time and overshoot by all methods, but CHR produces a better performance compared with Z-N SIMC, and AMIGO. The values of damping ratio are specified by solving 8. Obviously, both Z-N and AMIGO produced the lowest damping ratio compared with other cases.

$$\text{Damping Ratio } \zeta = \frac{-\ln [\rho OS/100]}{\sqrt{\pi^2 + \ln^2 [\rho OS/100]}} \tag{8}$$

Table 1. Response Time Comparison between Tuning Methods

Parameters	td(ms)	tr(ms)	ts(ms)	tp(ms)	SSt(ms)	Pos %	(ζ)
Z_N	13.7	80.4	1180	202	2000	47	0.233
SIMC	26.6	174	603	366	800	11	0.574
CHR	18.9	93.3	1110	234	1800	46.4	0.2374
AMIGO	30.5	163	996	372	1400	26.4	0.574



Figures 6(a-d). Step response comparison between tuning methods under study, a. Z\_N, B.CHR, c. SIMC, d. AMIGO

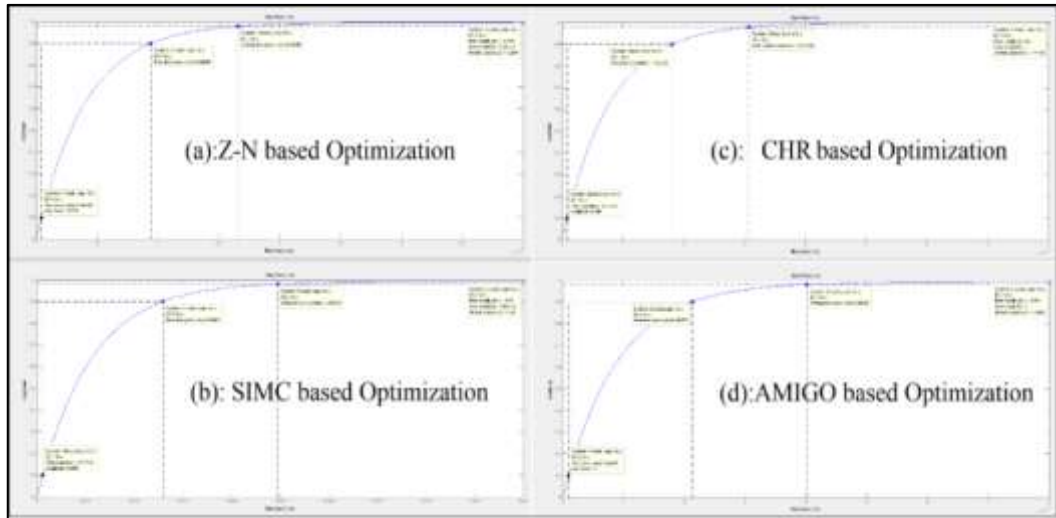
### 3.2. Analysis based Proposed Optimization Method

The proposed method relies on the optimization-based tune (*OBT*) using SISOtoolbox application. Figure 7(a-d), illustrates the step response of the system based proposed method, and the comparison parameters of step response are tabulated in Table 2. It is observed that eliminating overshoot achieved in both (*CHROBT*). and (*AMIGO<sub>OBT</sub>*), where it is quite small in (*Z<sub>N</sub>OBT*) and (*SIMC<sub>OBT</sub>*). Significantly, the response time parameters obtained by proposed much smaller and quite acceptable than those using tuning. But the significant results obtained by (*CHROBT*) compared with other tuning methods based (*SISO<sub>OBT</sub>*), produces magnificent shortest response tr,tp,ts, with zero overshoot, besides fewer iteration number. By contrast, the proposed method provides better performance and maximum reduction to all tuning methods with considered plant model to be measured a time response specification in Microsecond unit, that overcomes the major previous works in case of the majority of them not accomplish the highest reduction, despite using evolutionary algorithms to solve controller problems as in [24-31]. Table 3 shows the transfer function and proportional gains of proposed compensator based *OBT* for a different tuning methods. With concerning to Figures 8(a-b) and Table 4, the comparison of modification zeros location and adjusting compensator gains is presented, to show the effectiveness of using CHR tune based proposed methodology over other tuning understudy.

Table 2. Comparison Results between Tuning Methods based *SISO<sub>OBT</sub>* Technique

Parameters	td/μs	tr/μs	ts/μs	SSt/μs	(Pos) %	Iter.No
Z <sub>N</sub> <sub>OBT</sub>	41.5	899	1660	4000	2.22e-14	8
SIMC <sub>OBT</sub>	114	2470	4940	10000	6.66e-14	8
CHROBT	0.811	17.2	30.7	80	0	9
AMIGO <sub>OBT</sub>	95	2030	4010	8000	0	7

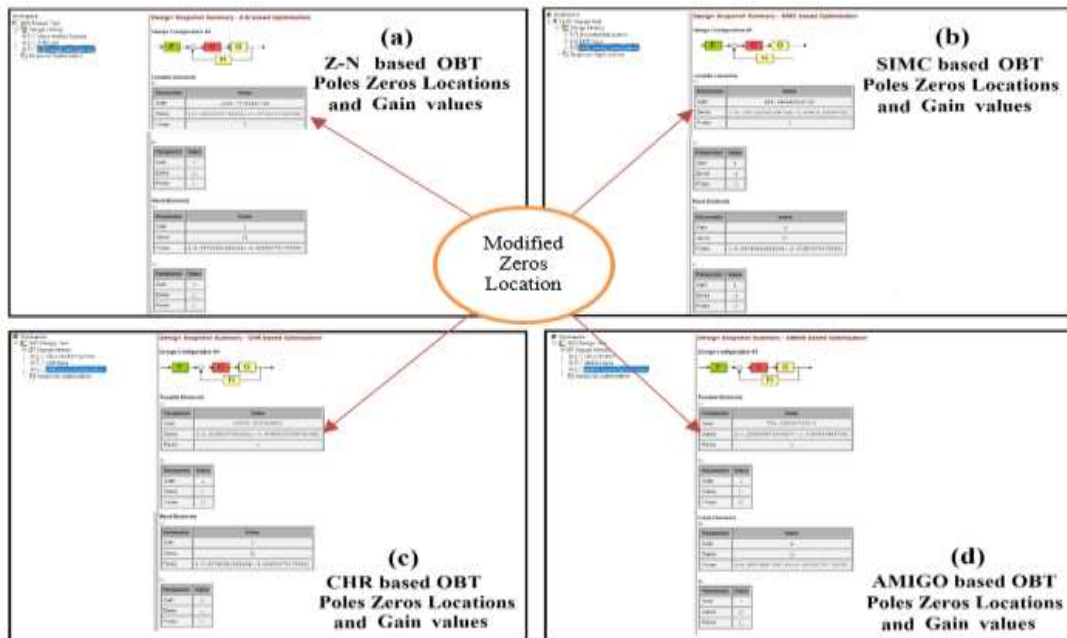




Figures 7(a-d). Step Responses Comparison between different tuning methods based  $SISO_{OBT}$ , a). $Z_{N_{OBT}}$ , b). $CHR_{OBT}$ ,c). $SIMC_{OBT}$ , d). $AMIGO_{OBT}$ .

Table 3. Final Parameters of Proposed Controller based Different Tuning Methods

Method	Compensator	Kp	Ki	Kd
$Z_{N_{OBT}}$	$1236.5(s + 2.296)(s + 0.4076)$	3.34e3	1.16e3	1.24e3
$SIMC_{OBT}$	$458.84(s + 0.09371)(s + 2.805)$	1.33e3	121	459
$CHR_{OBT}$	$63762(s + 2.609)(s + 0.00463)$	1.67e5	770	6.38e4
$AMIGO_{OBT}$	$556.34(s + 0.2251)(s + 1.701)$	1.07e3	213	556



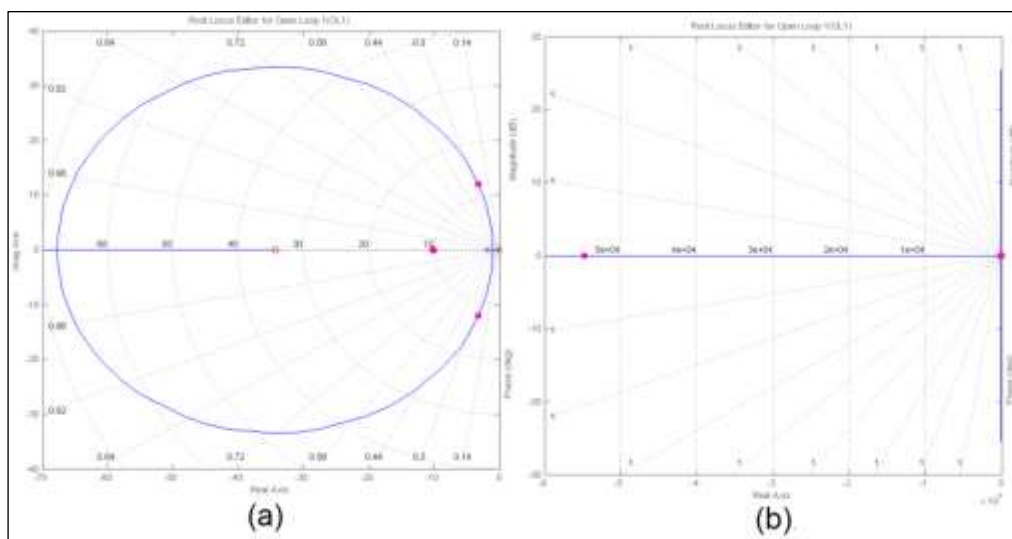
Figures 8(a-d). Zeros Poles location-based a). $Z_{N_{OBT}}$ ,b).  $SIMC_{OBT}$ ,c).  $CHR_{OBT}$ ,d).  $AMIGO_{OBT}$ .



Table 4. Comparison Modified Zeros Location and Gain Values based Proposed Methodology under Tuning Methods Understudy

	No of Zeros(Z)	Z1	Z2	Gain
$Z_{N_{OBT}}$	2 real	-2.296	-0.407	1236.8
$SIMC_{OBT}$	2 real	-0.093	-2.8	458.84
$CHR_{OBT}$	2 real	-0.608,	-0.0046	63762
$AMIGO_{OBT}$	2 real	-0.225	-1.7	556.34

Figures 9 (a, b) illustrate the root locus of controller based CHR lonely and  $CHR_{OBT}$  respectively, it is obviously to seen that the modification of zeros location based  $CHR_{OBT}$  produce high adjusting location compared with the lowest modification to using CHR method lonely. The final design with step response based  $CHR_{OBT}$  was simulated based Simulink as in Figure 10. Based on results and Figures 11, it can be observed that the step response based  $CHR_{OBT}$  exactly corresponds the design-based Simulink and produced higher reduction response time to be measured in Microsecond unit, which gives the capability to overcome the majority of previous works further tuning methods under study.



Figures 9(a,b). Root Locus, (a) Controller based CHR tuning, (b) Controller under CHR based proposed Methodology ( $CHR_{OBT}$ )

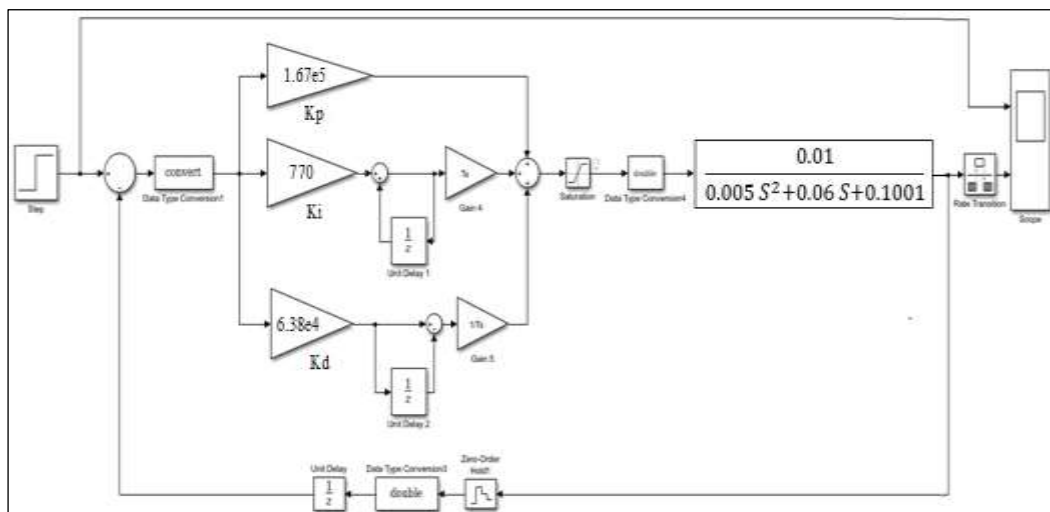


Figure 10. Final proposed design  $CHR_{OBT}$ -based simulink

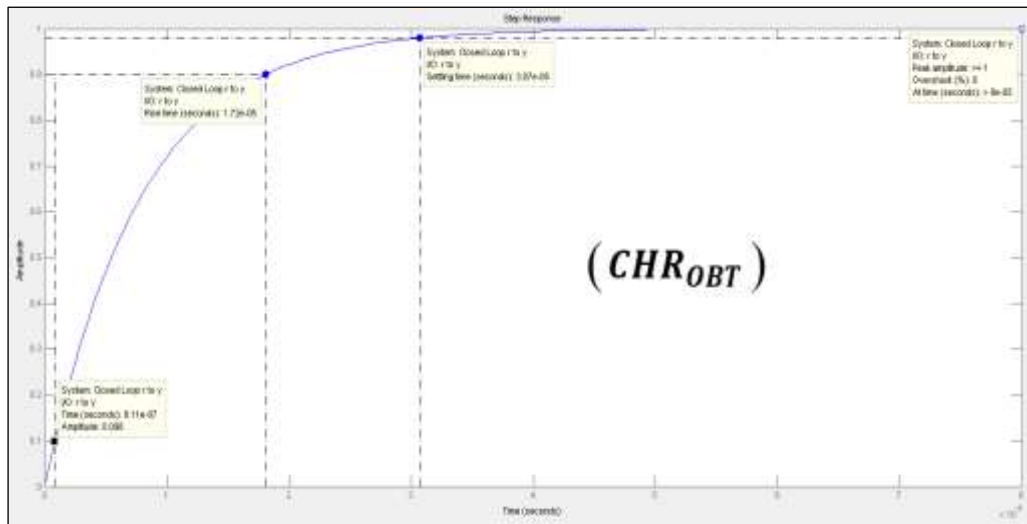


Figure 11. Step response based proposed controller  $CHR_{OBT}$

#### 4. CONCLUSION

This research has been done to examine the purpose behind the poor performance of PID controller-based DC motor through tuning or optimization algorithms when using them lonely. We proposed a novel method based on classical tuning methods Z N, SIMC, CHR and AMIGO to make a comparison in response time and to find out the proper tune, to be combined with SISO technique. The performance was analyzed and evaluated in term of minimization response time, optimal PID gains and poles zeros location. Step response of all methods and their system characteristics are compared with each other.

The results elucidate that all examined tuning methods based SISO technique  $SISO_{OBT}$  produce a magnificent performance over just using tuning methods. It was founded that  $CHR_{OBT}$  provides a higher reduction in response time parameters over existing methods were studied in this paper, particularly in  $t_d$  0.811  $\mu$ sec,  $t_r$  17.2  $\mu$ sec,  $t_s$  30.7  $\mu$ sec,  $SS_t$  80  $\mu$ sec, and  $Pos$  0%. Where, the improvement reduction compared with using CHR tune lonely for  $t_d$ ,  $t_r$ ,  $t_s$ ,  $SS_t$  closed to 23304, 5424, 36156, 22500 times respectively compared with just using a tune. The lowest minimization responses were appeared in  $AMIGO_{OBT}$  comparing with others  $t_d$  95  $\mu$ sec,  $t_r$  2030  $\mu$ sec,  $t_s$  4010  $\mu$ sec,  $SS_t$  8000  $\mu$ sec with  $Pos$  6.66e-14. Considerably, all models based proposed method produce an acceptable performance as far as response time and overshoot, yet  $CHR_{OBT}$  defeats others. This is ordinarily inside the required criteria for a DC motor controller and automated applications, in case of accurately adjusting proportional gains. In view of results, the proposed strategy provides a better computation efficiency to raise the robustness, stability, and proficiency, besides quickly calculations and convenient to use, further using with higher order system to improve transient response characteristics. It gives an excellent investigation into how the effectiveness of changing proportional gains to behavioral of PID controller to minimize transient response significantly.

By contrast, a significant priority of the proposed method comes from accurately adjusting proportional gains to eliminating overshoot and to minimize response time significantly. Further improvement of this study can be done by paying attention to use this technique with GA to enhance its performance for searching chromosomes. Practically, improved GA performance can be applied to optimize the hardware of DC motor controller significantly, by using Model-based Design to deploy the hardware on Field Program Gate Array FPGA /ARTY7.

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#### REFERENCES

- [1] M. Kaur., "Literature Review of PID Controller based on Various Soft Computing Techniques," *Int. J. Recent Innov. Trends Comput. Commun.*, pp. 5-8, Jun 2017.

- [2] K. J. Åström and T. Hägglund, "Revisiting the Ziegler-Nichols step response method for PID control," *J. Process Control*, vol. 14(6), pp. 635-650, 2004.
- [3] S. M. GirirajKumar, D. Jayaraj & A. R. Kishan., "PSO Based Tuning of a PID Controller for a High Performance Drilling Machine," *Int. J. Comput. Appl.*, vol. 1(19), pp. 12-18, 2010.
- [4] K. Nouman, Z. Asim & K. Qasim., "Comprehensive Study on Performance of PID Controller and its Applications," Proc. 2018 2nd IEEE Adv. Inf. Manag. Commun. Electron. Autom. Control Conf. IMCEC 2018, no. Imcec, pp. 1574-1579, 2018.
- [5] F. S. M. Alkhafaji and W. Z. W. Hasan, "A novel method for tuning PID controller," *J. Telecommun. Electron. Comput. Eng.*, vol. 10(1-12), pp. 33-38, 2018.
- [6] Š. Bucz and A. Kozáková, "Advanced Methods of PID Controller Tuning for Specified Performanc," *Long-Haul Travel Motiv. by Int. Tour. to Penang*, vol. i(tourism), p. 13, 2018.
- [7] M. M. R. A. Milani, T. Çavdar & V. F. Aghjehkand., "Particle swarm optimization-Based determination of Ziegler-Nichols parameters for PID controller of brushless DC motors," *INISTA 2012 - Int. Symp. Innov. Intell. Syst. Appl.*, 2012.
- [8] M. Shahrokhi and A. Zomorodi., "Comparison of PID Controller Tuning Methods," Proc. 8th Natl. Iran. Chem. Eng. Congr., pp. 1-12, 2002.
- [9] R. Sen, C. Pati, S. Dutta & R. Sen., "Comparison Between Three Tuning Methods of PID Control for High Precision Positioning Stage," *Mapan - J. Metrol. Soc. India*, vol. 30(1), pp. 65-70, 2014.
- [10] J. Paulusová and M. Dúbravská, "Application of Design of Pid Controller for Continuous Systems," *Humusoft.Cz*, (1), pp. 2-7, 2012.
- [11] V. Chopra, S. K. Singla & L. Dewan., "Comparative analysis of tuning a PID controller using intelligent methods," *Acta Polytech. Hungarica*, vol. 11(8), pp. 235-249, 2014.
- [12] H. Zhang, Y. Cai & Y. Chen., "Parameter optimization of PID controllers based on genetic algorithm," 2010 Int. Conf. E-Health Networking, Digit. Ecosyst. Technol. EDT 2010, vol. 1, pp. 47-49, 2010.
- [13] R. S. Naik, P. G. Student, A. Pradesh & A. Pradesh., "Tuning of PID Controller by Ziegler-Nichols Algorithm for Position Control of DC Motor," *IJISET - Int. J. Innov. Sci. Eng. Technol.*, vol. 1(3), pp. 379-382, 2014.
- [14] D. Penchalaiah, G. N. Kumar, M. M. Gade & S. E. Talole., "Optimal Compensator Design using Genetic Algorithm," *IFAC-PapersOnLine*, vol. 51(1), pp. 518-523, 2018.
- [15] S. R. Santhiya, F. S.V, S. S. S. Mol & V. Suresh., "Optimized PID Controller for Low Power Applications using Particle Swarm Optimization," *Int. J. Eng. Res. Technol.*, vol. 8(04), pp. 8-11, 2019.
- [16] J. B. Odill, M. N. M. Kahar & A. Norahzia., "Parameters-tuning of PID controller for automatic voltage regulators using the African buffalo optimization," *plos\_one*, pp. 1-12, 2019.
- [17] E. E. Vladu and T. L. Dragomir, "Controller Tuning Using Genetic Algorithms," Proc 1st Rom. Jt. Symp. Appl. Comput. Intell., pp. 1-10, 2004.
- [18] N. Ankita and M. Singh, "Research Paper Study of Tuning of PID Controller by Using Particle Swarm Optimization," Proc. BITCON-2015 Innov. Natl. Dev. Natl., 2015.
- [19] I. Hassanzadeh, S. Mobayen & G. Sedaghat., "Design and implementation of a controller for magnetic levitation system using genetic algorithms," *J. Appl. Sci.*, vol. 8(24), pp. 4644-4649, 2008.
- [20] O. Chao and L. Weixing, "Comparison between PSO and GA for parameters optimization of PID controller," 2006 IEEE Int. Conf. Mechatronics Autom. ICMA 2006, vol. 2006, pp. 2471-2475, 2006.
- [21] D. P. Sai., "IMC based PID Controllers Retuning and It's Performance Assessment," *Int. J. Appl. Eng. Res.*, vol. 13(22), pp. 15922-15925, 2018.
- [22] T. M. S. Mohd S.M.A., "Tuning Methods of PID Controller for DC Motor Speed Control Tuning Methods of PID Controller for DC Motor Speed," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 3(December), pp. 343-349, 2016.
- [23] F. S. M. Alkhafaji, W. Z. W. Hasan, M. M. Isa & N. Sulaiman., "Proposed a Novel Method for Optimization DC Motor Controller," IEEE 5th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA 2018). Songkhla, Thailand, pp. 28-30, 2018.
- [24] M. A. Shamseldin, M. A. Eissa & A. A. El-samahy., "Practical Implementation of GA-Based PID Controller for Brushless DC Motor," 17th Int. Middle East Power Syst. Conf. Mansoura Univ. December 15-17, 2015, Dec 2015.
- [25] T. Vijayakumar, S. Muthukrishnan & G. Muruganath., "Genetic Algorithm Based Speed Control of PMDC Motor Using Low Cost PIC 16F877A Microcontroller," *Circuits Syst.*, vol. 07(08), pp. 1334-1340, 2016.
- [26] B. Bourouba and S. Ladaci, "Comparative performance analysis of GA, PSO, CA and ABC algorithms for fractional PI<sup>λ</sup>D<sup>μ</sup> controller tuning," Proc. 2016 8th Int. Conf. Model. Identif. Control. ICMIC 2016, (2), pp. 960-965, 2017.
- [27] Falih S. M. Alkhafaji et al., "Robotic Controller: ASIC Vs FPGA - A Review" *Journal of Computational and Theoretical Nanoscience (ASP)*, vol. 14, pp. 1-16, 2018.
- [28] S. K. Suman and V. K. Giri, "Speed Control of DC Motor Using Optimization Techniques Based PID Controller," 2nd IEEE Int. Conf. Eng. Technol. (ICETECH), 17th 18th March 2016, Coimbatore, TN, India, Mar 2016.
- [29] W. M. Elsrogy, N. K. Bahgaat, M. El Sayed & M. M. Hassan., "Speed Control of DC Motor Using PID Controller Based on Changed Intelligence Techniques," *Int. J. Swarm Intell. Evol. Comput.*, vol. 07(01), 2018.
- [30] S. K. Raja, V. P. Badathala & S. S. K., "LFC Problem by Using Improved Genetic Algorithm Tuning PID Controller," *Int. J. Pure Appl. Math.*, vol. 120(6), pp. 7899-7908, 2018.
- [31] N. Ismail, I. Nursalim, H.M. Saputra & T.S. Gunawan., "Implementation of fuzzy logic control system on rotary car parking system prototype," *Indonesian Journal of Electrical Engineering and Computer Science (IJECS)*, vol. 12(2), pp. 706-715, 2018.

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