A comparative study of power consumption of electric power steering system

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Optimal Design of Electric Power Assisted Steering System (EPAS) Using GA-PID Method

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Abstract

The introduction of Electric Power Assisted Steering (EPAS) system is gradually replacing the conventional steering system in modern cars. The main advantage of EPAS system is the ability to minimise energy consumption. This paper discusses the implementation of GA-PID algorithm to realise the potential of energy reduction as compared to conventional PID method. A brushes DC motor is mounted on the steering column to provide an assist torque to the driver. This configuration is known as C-type EPAS system. The results have shown GA-PID controller is bale to minimize energy consumption as compared to PID controller.

Keywords: Electronic Power Assited Steering System (EPAS) , C-type EPAS, GA-PID, electric vehicle .

Nomenclature

J_m	Motor moment inertia
B_m	Motor damping
K_b	Motor EMF constant
K_a	Motor torque
K_m	Motor stiffness
L	Motor inductance
R	Motor resistance
J_s	Steering wheel moment of inertia
K_s	Steering column stiffness
B_s	Rack damping
M_r	Rack and wheel assembly mass
G	Motor gear ratio
Rs	Pinion radius
Tc	Sensor measurement torque
Td	Driver torque
Ta	Assist torque
θ_s	Steering wheel angle
θ_m	Motor rotation angle

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1. Introduction

The limitation of battery capacity has always been a major concern in electric vehicle (EV). Thus, several researchers have made an effort to emphasize the importance of energy efficiency in each auxiliary of EV system. Mechanical steering system or Hydraulic Assisted Power Steering (HPAS) are no longer practical in EV application. This is due to a constant energy supply from battery is required to maintain the pressure in the hydraulic pump. It also requires regular maintenance to the hydraulic mechanism system. Meanwhile, EPAS system is only consumed energy when the steering wheel is turned. It also requires no liquid medium, fewer mechanical components, less fault tolerance and most importantly environment friendliness [1-3]. A typical EPAS system necessitates; the steering torque, vehicle speed and road condition as input parameters to provide the real time assistance torque through assist-motor [4]. It will provide the best steering feel in variety of operating conditions. There are three conFigurations of EPAS system that have been used widely; known as column-type (C-EPAS), pinion-type (P-EPAS) and rack-type (R-EPAS). It is basically represents the location of assist motor is mounted. C-type configuration is normally equipped in compact car which has a load of 6kNm. The load requirement for for these three types of EPAS system is tabulated in Table 1.

Table 1: Load Requirements for EPAS

Types of EPAS	Car Size	Load
C-type	Small	6 kN
P-type	Medium	8 kN
R-type	Large	12 kN

The main component for EPAS system is the electric motor. The selected motor should produce a smooth torque with minimum ripple, high efficiency, low inertia, fault-tolerance capability and minimum package size and weight [5]. Different types of motor have been proposed by many researchers for EPAS applications such as DC motor, brushless DC motor and synchronous PM motor [6].

2. Principle of C-type EPAS System

A typical schematic diagram of C-type conFiguration is illustrated in Fig 1. The systems consists of a steering torque sensor, a vehicle speed sensor, ECU, motor and assist mechanisms such as gear box and gear rack.

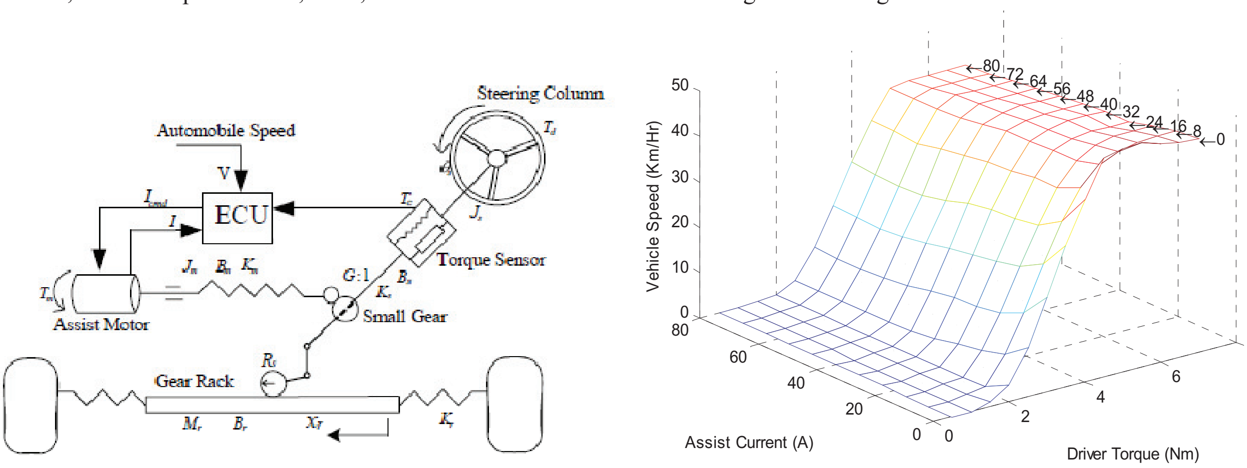

Fig 1: Column Electric Power Steering System Model [4] and Assist-Current Curve

When the system is activated, the driver torque signal and vehicle speed signal are transmitted to ECU. These two signals will be used to calculate the best assist torque for the driver using the assist boost curve. The boost curve is normally represented in a look up table because it is influenced by many factors and nonlinear. The relationship of real-time vehicle speed sensor and the steering wheel torque is expressed as $i_a = B(T_C, V_{speed})$. The main objective of controller is to produce an accurate current tracking to the motor. EPAS can be divided into four subsystems which are (1) Steering column and driver torque (2) assist motor (3) road condition and friction and (4) rack and pinion. Each subsystem is represented in equation (1) to (9). The model is simulated using MATLAB/ Simulink as illustrated in Fig 2. The mathematical model of C-type EPAS system in Fig 2 was developed and derived according to Newton's Laws of motion. All parameters used in this simulation are depicted from reference [4]. In this paper, BCGA-PID has been implemented in closed loop structure. The target current from boost curve to motor is compared with the actual output current of the motor.

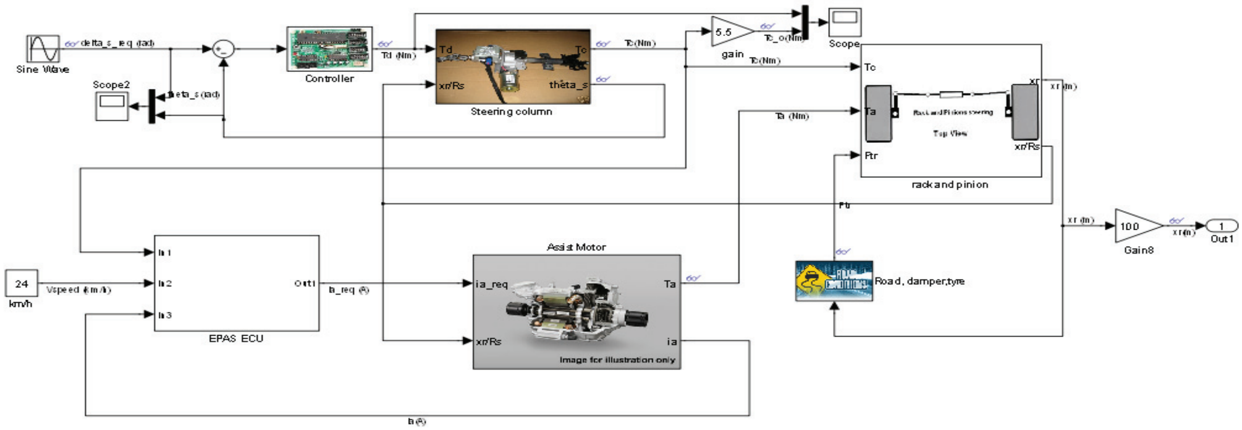

Fig 2: Simulink Model C-Type EPAS System

<u>Steering Column, Driver Torque</u>

$$J_s\ddot{\theta}_s + B_s\dot{\theta}_s + T_c = T_d \tag{1}$$

$$T_d = (\Delta\theta_s - \theta_s)(K_p + K_i\frac{1}{s} + K_d s) \tag{2}$$

$$T_c = K_s(\theta_s - \frac{x_r}{R_s}) \tag{3}$$

<u>Assist Motor Model</u>

$$J_m\ddot{\theta}_m + B_m\dot{\theta}_m = T_m - T_a \tag{4}$$

$$T_m = K_a i_a \tag{5}$$

$$U = Ri_a + Li_a + K_b\dot{\theta}_m \tag{6}$$

$$T_a = GK_m(\theta_m - G\frac{x_r}{R_s}) \tag{7}$$

$$I = i_a + K_w\theta_w \tag{8}$$

$i_a = B(T_C, V_{speed})$; B= boost curve look-up table

<u>Road Conditions and Friction</u>

$$F_t = J_w\ddot{x}_r + B_w\dot{x}_r + K_w x_r + CF_w sign(\dot{x}_r) \tag{9}$$

<u>Rack and Pinion Displacement</u>

$$M_r\ddot{x}_r + B_r\dot{x}_r - \frac{T_c}{R_s} = \frac{T_a}{R_s} - F_{TR} \tag{10}$$

3. Genetic Algorithms

Genetic algorithm [6] is a general-purpose optimisation algorithm based on the mechanics of natural selection and genetics, which work with a population of solutions. A fitness value, derived from the problem's objective function is assigned to each member of the population. Individuals that represent better solutions are awarded higher fitness values, thus enabling them to survive more generations. Starting with an initial random population, successive generations of population are created by the genetic operators reproduction, crossover and mutation to yield better solutions, which approach the optimal solution to the problem. The GA repeats the above steps until the predetermined criteria are met. In genetic algorithm, all the variables of interest must be encoded as binary digits (genes) and a collection of binary digits further forms a string (chromosome) and this representation is called binary-coded GA (BCGA). After a manipulation of BCGA, the final binary digits are then decoded as original real numbers. Genetic algorithms maintain a group of chromosomes, called the population, to explore the search space and solve a problem. In every generation, the performance of each chromosome is evaluated for fitness in order to measure how close it is to the solution according to a predefined objective function. The genetic operators, that are crossover and mutation, are used to produce a new population of individuals in the BCGA. The process is repeated until a solution is found or the maximum number of iterations is reached. More details on the mechanism of GA can be found in [6]. There are four crucial parameters affecting the performance of GA: (i) population size, (ii) number of generations, (iii) crossover rate, and (iv) mutation rate. Larger population size (i.e. hundreds of chromosomes) and a large number of generations (thousands) increase the likelihood of obtaining a global optimum solution, but substantially increase processing time [7]. Crossover is used in producing new chromosomes in the BCGA. It takes two chromosomes and swaps part of their genetic information to produce new chromosomes. The swapping points are randomly chosen. The simplest form of crossover is that of single-point crossover. The mutation operator in BCGA is randomly applied with mutation probability, P_m to provide a guarantee that the probability of searching any given string will never be zero. It also acts as a safety net to recover good genetic material that may be lost through the action of selection and crossover. Binary mutation flips the value of the bit at the loci selected to the mutation point. Given that mutation is generally applied uniformly to an entire population of strings, it is possible that a given binary string may be mutated at more than one point.

4. PID Controller

PID controller is a generic control mechanism widely used in industrial control systems. Since its introduction, conventional PID control has been widely used for example in chemical and paper industries, where about 97% of controllers have the PID structure [8] This could be due to their low cost, inexpensive maintenance, as well as simplicity in controller design and operation [9] The widespread use of this controller has led to research towards finding optimal values of the PID controller parameters such as classical tuning rules for the PID controller based on trial and error [10] and pole placement [11]. Unfortunately, it has been difficult to tune PID controller gains accurately because many industrial plants are often very complex consisting of issues such as higher order, time delays and nonlinearities [18]. Some disadvantages of the classical techniques for tuning PID controllers are: (i) excessive number of rules to set the gains, (ii) inadequate dynamics of closed-loop responses, (iii) difficulty to deal with nonlinear processes, and (iv) mathematical complexity of the control design [12]. To overcome these difficulties, various types of modified conventional PID controllers such as autotuning and intelligent PID controllers have lately been developed in order to improve the traditional methods in tuning the PID controller parameters [13, 14, 15]. Therefore, the BCGA optimisation method can provide parameters tuning while reducing oscillation in a closed-loop environment as described in Fig 3.

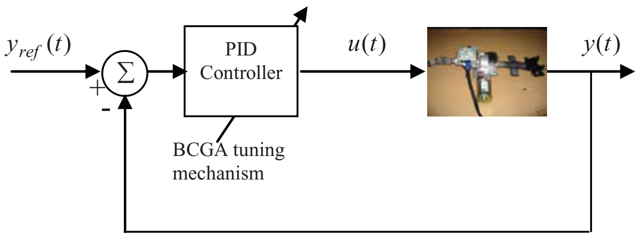

Fig 3: PID controller with BCGA tuning mechanism for the EPAS

The difference between the desired set point and actual output is recorded as error :

$$e(t) = y(t) - \hat{y}(t) \tag{13}$$

where $y(t)$ is the actual current of the EPAS $\hat{y}(t)$ is the predicted current of the EPAS of the beam. The mean-squared error (MSE) is defined and used to form the objective function of the optimisation process. In other words, the parameters should be estimated so that the MSE converges to zero.

$$\text{Objective function} = \frac{1}{N}\sum_{t=1}^{N}\left|y(t) - \hat{y}(t)\right|^2 \tag{14}$$

where, N=1000 represents number of data points. There are a few standard objective functions which are commonly used to evaluate process function. Among these standard functions, the MSE objective function is the most important and is defined as equation (14) [16]. This objective function originally became popular in estimation problems considering unbiased estimators of unknown parameters [17]. The considered objective function is a squared function, which is evaluated as the mean over the set of data, and minimised in order to optimise the considered modelling design. Therefore, MSE is used as objective function. Among the researches that have used MSE as an objective function for computational intelligence optimisations in their works are [18, 19].

5. Results and Discussion

The main focus is to rectify the energy consumption of two different control algorithms of PID and GA-PID. The control scheme structure of the assist motor is shown in Fig 4. The movement of rack is a summation of driver torque, assist motor minus road and friction model. The road and friction are modeled as in equation (9).

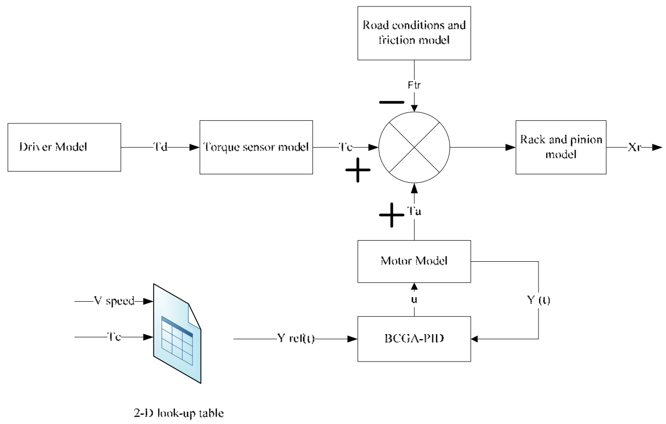

Fig 4: C-EPAS Control Structure

Initial test is conducted to justify all parameters for PID controller and rectify the potential of power consumption EPAS system as illustrated in Fig 5. The PID controller only provides good control signal and capable to control current accordingly. The simulation is completed for vehicle speed of 45 km/h and a distributed random numbers that represent driver's torque. PID controller is able to control the required assist current to the motor. However, the PID parameters are defined using trial and error method which is a very time consuming process.

Therefore, by introducing the BCGA to optimize the PID could possibly facilitate the tuning process. The BCGA has made a quicker tuning of all PID parameters instead. The BCGA algorithm thus described in Section 3 can be formulated as:

Initialise individuals in the population randomly in the search space.
Evaluate objective function of the population
Repeat
  Apply a fitness value to the individuals
  Perform competitive selection using (Stochastic universal sampling)
  Apply genetic operators to generate new solutions:
    Crossover
    Mutation
  Evaluate Solutions in the population
Until convergence criteria is satisfied

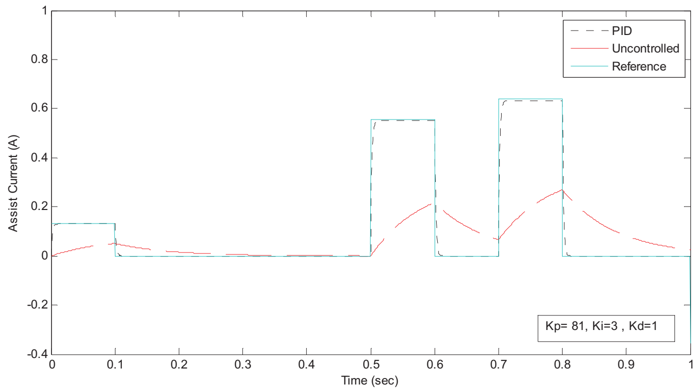

Fig 5**:** Controller Performance between PID and Uncontrolled System

The BCGA technique described above is used for GA-PID controller tuning for EPAS system. The characteristic parameters of the BCGA used are presented in Table 2. GA-PID control strategy as shown in Fig 6 has demonstrated that there is not much different on the controller output compare to PID. But a closer view has shown that it slightly produced better control performance. The GA-PID and PID parameters are tabulated in Table 3.

Table 2: Characteristic parameters of the BCGA used for parametric modeling

Characteristics	Items
Number of iterations	50 iterations
Number of individuals	50 individuals
Number of variables	3 (*Kp, Ki and Kd*)
Generation gap (how many new individuals are created)	0.8
Selection	SUS
Recombination probability	0.8
Mutation probability	1/3 (number of variables)

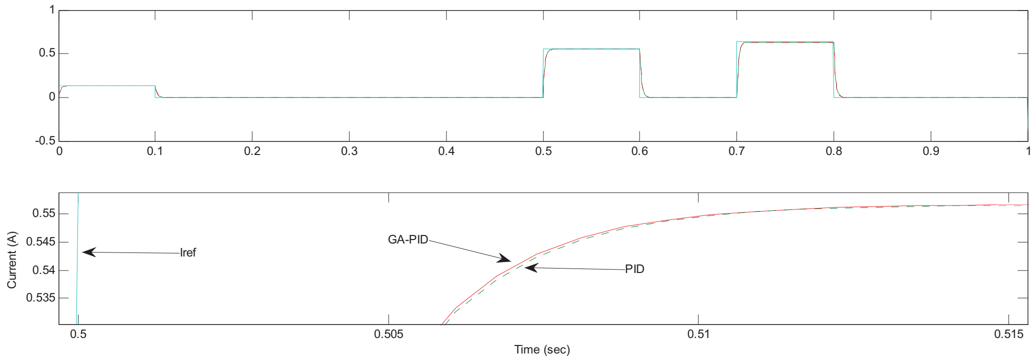

Fig 10: Controller performance between PID and GA-PID

Table 3**:** Parameters of the PID and GA-PID

Parameter	PID	GA-PID
Kp	78	80.1008
Ki	3	3.8387
Kd	1	1

The GA-PID method consumed an average of 13% less power compared to PID as illustrated in Fig 7. The simulation is completed with 40 km/h of vehicle speed and a random driver's torque. The GA-PID also capable to retain power consumption when sudden a drop of the driver's torque occurs. This contributes to an average increase of power consumption using PID controller.

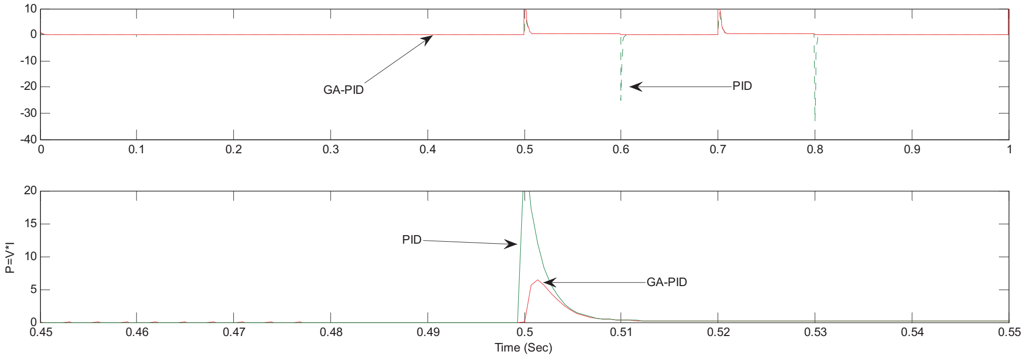

Fig 7: Power Consumption of GA-PID and PID

Another test is conducted when the vehicle speed is increased using ramp function with slope 1 km/h and the torque is a random signal. The power consumption using GA-PID has shown an average reduction of 75% compared to PID as shown in Fig 8. When a rapid driver's torque is applied with increasing vehicle speed the power consumption increased significantly with PID controller. However further analysis has to be done to illustrate the power consumption such as in parking situation where the vehicle speed is zero and a rapid changes of driver's torque. This initial investigation is merely to justify and to make assessment the potential of other controller algorithm for EPAS system.

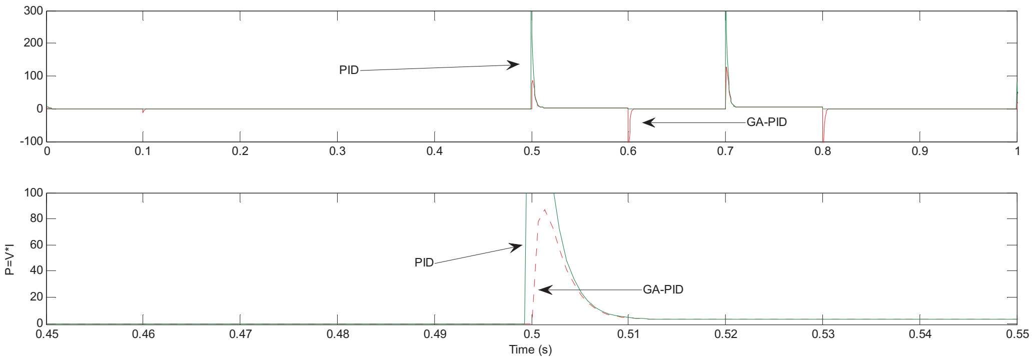

Fig 8: Power Consumption of PID and GA-PID

Conclusion

In this exercise two situations of driving scenario are evaluated; dynamic and constant vehicle speed. The results indicated that GA-PID algorithm consumed lower power consumption compared to PID. However, further analysis has to be carried out to rectify parking situation as well as harmonic torque applied to steering wheel. The GA-PID also demonstrates the potential to further research in realizing energy efficiency of EPAS system. But most importantly, cost effective to replace the existing steering system and would benefit the automobile industry largely

References

[1] Dariusz Z. 2011. Modelling of EPS Type Steering Systems Including Freeplay and Friction in Steering Mechanism. Journal of KONES Powertrain and Transport, Vol 18.1. pp 689-696.
[2] Xin L, Xue P.Z.and Jie C. 2009. Controller Design for Electric Power Steering System Using T-S Fuzzy Model Approach. International Journal of Automation and Computing. 6(2). pp 198-203.
[3] Chunhua,H. 2008. Modelling and Simulation of Automotive Electric Power Steering System. IEEE Second International Symposium on Intelligent Information Technology Application. pp 436-439.
[4] Huaiquan, Z. and Shuanyong, C. 2011. Electric Power Simulation Analyze Based on Fuzzy PID Current Tracking Control. Journal of computational Information System 7:1. Pp 119-126.
[5] Rakan, C. C. 2009. Torque Estimation in Electrical Power Steering Systems. Vehicle Power and Propulsion Conference, 2009. VPPC '09. IEEE. pp 790-797.
[6] Goldberg, D. E., 1989. Genetic algorithm in search, optimisation and machine learning, New York, Addison-Welsley.
[7] Elbeltagi, E., Hezagy, T. and Grierson, D., 2005. Comparison among five evolutionary-based optimization algorithms. Advanced Engineering Informatics, 19, 43-53.
[8] Kumar, V., Rana, K. P. S., and Gupta, V., 2008. Real-time performance evaluation of a Fuzzy PI + Fuzzy PD controller for liquid-level process. International Journal of Intelligent Control and Systems, 13, (2), 89-96.
[9] Ziegler, J. G., and Nichols, N. B., 1942. Optimum settings for automatic controllers. Transactions ASME, 64, 759-768.
[10] Åström, K. J., and Hagglud, T., 1995. PID controller: theory, design and tuning, USA, Research Triangle Park, NC
[11] Gaing, Z. L., 2004. A particle swarm optimisation approach for optimum design of PID controller in AVR system. IEEE Transactions on Energy Conversion, 19, 384-391.
[12] Coello, C. A. C., Veldhuizen, D. A. V., and Lamount, G. B., 2001. Evolutionary algorithms for solving multi-objective problems, Kluwer Academic Publishers.
[13] Toha, S.F. and Tokhi, M.O., 2011. PID and inverse model based control of a twin rotor system. Robotica, 29 (6), 929-938, DOI: 10.1017/S0263574711000154
[14] Mohd Khair. H, Aishawarya. K, Ribhan Zafira A.R and Siti Anom.A, Design a PID Controller for a Constant Speed of Combustion Engine, Australian Journal of Basic and Applied Sciences, 5(12): 1586-1593.
[15] Steenackers, G. and Guillaumea, P., 2008. Bias-specified robust design optimization: A generalized mean squared error approach. Computers and Industrial Engineering, 54, (2), 259-268
[16] Berger, J., 1995. Statistical Decision Theory, Springer-Verlag, Berlin, HeidelbergElbayomy, K. M., Zongxia, J. And Huaqing, Z., 2008, PID Controller Optimization by GA and Its Performances on the Electro-hydraulic Servo Control System, Chinese Journal of Aeronautics, 21 (4), 378-384.
[17] Toha, S.F. and Tokhi, M.O., 2010. Parametric modelling application to a twin rotor system using RLS, genetic and swarm optimisation techniques Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 224, (9), 961-977, DOI: 10.1243/09544100JAERO706.

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