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A Comparative Analysis of Optimization Algorithms for Self Tuning PID Controllers

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ABSTRACT

In recent days, Proportional–Integral-Derivative (PID) controller shows a rapid growth because of its tremendous utility of the services for the purpose of control engineering applications. The PID tuning are the major concern in the process of controller framework. Hence, the process of self-tuning becomes an important aspect. The purpose of this study is to investigate the framework of PID controller for the online self-tuning using Particle Swarm Optimization (PSO) algorithm. PSO algorithm has been chosen for its unique nonlinear and multidimensional function optimization characteristics. An important concern is to select the best fitness function value and the particles initial range to solve the problems. PID controller is a controller which is universally accepted due its distinctive structures. This is mainly used in most of the industries for the control applications. Moreover, different fitness functions give different time response and also the smaller range of the particle initialization should be taken for the better performance of the System. It is also concluded that it takes only less time for the evolutionary peers due to uncertain online generation system with linear inertia weight. There are different conventional algorithms like genetic algorithm, ant colony, and Dynamic firefly algorithm. In this survey, various algorithms are analyzed. From the analysis it is understood that each technique has its own merits and demerits. Thus the survey aims at analyzing different algorithms that is approached for online self-tuning of PID controller.

Keywords: *Particle Swarm Optimization (PSO), Proportional –Integral-Derivative (PID) controller*

1. INTRODUCTION

In the past decades, an industrial control techniques have more advanced approaches and plays a significant role. The control methods are studied thoroughly to analyze the best controller for the industrial applications. Proportional–Integral-Derivative(PID) controller have been used for many applications because to its simple and robustness. Unluckily tuning is a difficult part in PID controller where the industrial plants faces more glitches like delay time, high order and non-linearity. Several methods are introduced to tune the PID controller properly. Initially the classical tuning rules are used but it is difficult for defining the optimal and nearly available PID parameters in numerous industrial plants. For this purpose, additional new features are needed and it is one of the increasing concern of PID controllers.

In order to enhance the performance of the controller for the comprehensive range of plants, a numerous artificial intelligence (AI) methods are employed. The parameters involved in PID controllers are tuned appropriately using AI techniques such as neural network, fuzzy system and neural-fuzzy logic.

Higher efficiency methods are presented for the random searching to acquire the global optimum solution across problem space. The random searching methods are Genetic Algorithm (GA) and simulated annealing. The GA is quicker approach because of its parallel search techniques that compete with natural genetic operations. A global optimization is performed well in GA which makes the GA as more efficient algorithm. Though GA has been extensively used for numerous control application, however there are huge computational efforts due to its genetic operations. To overwhelm these issues, the real value is represented on GA for statistical function optimization across the binary encoding. The complex optimization problems are solved using GA approaches, still there are deficits over the performance. For highly epistatic objective functions the GA is inefficient because the optimized parameters get correlated and the average fitness is more. And also the performance and the searching ability is despoiled due to its premature convergence.

Particle swarm optimization (PSO) is a recent heuristic algorithm which has been developed widely for the industrial control applications. A constant nonlinear optimization problems are solved using this effective algorithm. PSO achieved great quality solution and steady convergence characteristic than other approaches. Researchers are focused more on the PSO to prove its potential with reduced complexity in operational problems. Most of the researchers presented PSO approach and compared it with traditional methods to prove PSO efficiently in practical power system applications. PSO is outstanding technique to find the optimal solution for the parameter problems in PID controller. Further studies will be done on PSO to enhance the efficiency much better than other approaches.

2. RELATED WORK

A. Review on PID Controllers

In 1996, Poulin, Pomerleau, Desbiens, & Hodouin described a practical design of PID controller's auto-tuning

(AAC) and the adaptive single-input-single-output (SISO)[19]. This can have capability to control the stable processes, integrator processes, standard aperiodic processes and unstable processes. Along with an estimation of recursive parameter, this process utilized the identification based on explicit approach. This kind of estimation is the second-order with the delay model. By deployed the cancellation of pole-zero, specifications of supreme peak resonance, phase margin along with the delay extraordinary considerations, unstable zeros, and finally poles, the approximation for the minimization is carried out.

These are based on the ITAE criterion which is used for tuning in the regulator approach. Additionally, the data filtering, Mechanism of tuning, the supervisory shell and the identification have been described. The Proportional-Integral(PI) and tuning of PID's beneficial strategies are mentioned for the processes of SISO. By using a benchmark test along with the profitable adaptive PID controllers such as the Leeds & Northrup Electromax V, Foxboro 76OC and the Fisher DPR 910, the performance of the AAC have been compared. Bansal, Sharma & Shreeraman reviewed the recent and the classical techniques that were used for PID tuning [22].

The active research has been undertaken on the PID tuning controller where most of the industrial oriented operations are performed. Those reviewed techniques were categorized as classical techniques and optimization techniques that is designed for tuning drives. The comparison the chief objective of this work is to offer an inclusive reference source for the members those working in PID controllers.

B. PSO based PID controllers

Lian, Jhang, & Tian realized the maximum powder point tracking (MPPT) method related to perturb and observer(P&O) combined with particle swarm optimization and it was also tracked the global maximum point (GMP) [15]. It was done with the combination of perturb and observe (P&O) and particle swarm optimization. The P&O method was utilized to allocate the nearest local maximum and PSO searched the GMP. MPPT method was used to track the GMP, when the photo voltaic (PV) panel was partially shaded by clouds, snow, trees and buildings. The search space was reduced to allow the GMP for quickly obtaining the advantage of the hybrid method where the search space was reduced, consequently the convergence time was also enhanced.

Khooban & Niknam presented a new method for realizing the load frequency across multi area systems and to identify the parameters of PI controllers [11]. A new strategy using self-adaptive modified bat algorithm and fuzzy logic approach in which the controller provides better stability, strength beside suspicions produced by outward disturbances and the problems due to temporary changing aspects. The four-area connected power system was used as a control design methodology for this approach that signifies large scale power system. To acquire better performance, the parameters and member functions were optimized in this proposed controller. The efficiency of this controller was higher when compared to other conventional scheme.

Lee & Chen described the novel approach to save the power on the servers through controlling the speed of the fan [13]. The higher demand for this approach was due to the presence of high density servers. It studied a PID controller along with PID neural network with optimized fan power of transient state temperature response to cool the servers. To control the power intake over cooling through the rapidity of fan, a third order nonlinear curve fit was used to create the fan power model and also a server mockup system act out 1U rack server was prepared due to its complex and nonlinear thermal model system. A time domain criteria was utilized in this method. Thus the different experiments were done with proposed controller while server functioned from smaller range to greater power. Finally, 14% of the power on the server was saved when it allows overshoot in the components for providing the time-saving strategy with the help of PID controller tuning to control the fan speed of the server for the period of lower power consumption.

Chatterjee & Mukherjee propose an optimum value of PID controller using low pass filter in the automatic voltage regulator (AVR) was obtained by applying teaching–learning based optimization (TLBO) technique [4]. With this proposed TLBO based PID controller using first order low pass filter was compared with latest state of the art literatures algorithms in terms of AVR voltage response. The control strategy used here was more beneficiary because of dynamic responses across the comprehensive range of parametric variations in system. To obtain the online, off-nominal operating circumstances over the energetic responses of considered model a fast performing Sugeno fuzzy logic technique is applied. And also the performance was analyzed with the robustness of the system. The voltage response along with different model parameter was analyzed. Thus the proposed method shows that the TLBO based PID controller was important optimization tool in the area of AVR system. In this paper Jain, Gupta, & Parmar studies the PID controllers which is broadly used in industrial plants due to simple structure of PID controller and also it has perfect control structure [9].

The implementation was easy. In industrial applications the parameter variations make the system unbalanced. Therefore, the control engineers were focused on the automatic tuning processes. The techniques such as Genetic algorithm(GA), Ant colony optimization and particle swarm optimization were analyzed. The tuning constants were appropriately chosen to improve the steady state characteristics for acquiring better performance. Guo, Ren, & Liu labelled for optimizing the parameters involved in the controller using chaotic particle swarm optimization (CPSO) method [6]. In this approach the initial distribution was done with original particles for the better performance and also to avoid the local minimums using spatiotemporal chaos map which was produced by multi-dimensional chaotic sequences. The multi objective weight selection problem was avoided using pareto optimal solutions.

The searching capability and time consumption was improved with the use of PSO algorithm. This paper examines the control parameter for optimization and it can also have applied for the entire converter topology and parameter optimization. Qazi, Mustafa, Sultana, & Hussain presented a novel approach for enhancing the power quality of autonomous Micro grid system (MGS) through controlling flow of active and reactive power in grid connected mode of MGS [20]. Initially MGS was simulated with static PI controller, but due to unexpected variations on the operating condition of the system no optimal results were obtained. Thus to attain optimal results a particle swarm optimization was used.

The results showed that MGS acquired optimal results through sustaining the sinusoidal voltage and current waveform with least harmonic distortions. The advantages were that the distributed power system acquired more life span and power of the system was saved from overheating. Barisal & Mishra presented an automatic control of power generation across the uneven areas using various power generation sources such as thermal, wind, hydro and diesel power plant [3]. In this approach three optimization techniques specifically Particle swarm optimization, Bacteria Foraging algorithm and Improved PSO (IPSO) were used for tuning the PID controller of power system. To get an enhanced PSO technique, a restraint treatment mechanism named dynamic search space squeezing strategy was developed for the quick optimization process in PSO algorithm.

Diverse sources of power were examined for the two uneven power distributed areas using IPSO optimized PID controller including the consideration of 1% of step load perturbation of cost function integral of time multiplied absolute error for either one or all control areas. Here instead of AC tie lines the AC or DC parallel lines were considered among the areas that has to be controlled for accomplishing dynamic performance of the system. When performing sensitive analysis on this proposed approach, the parameters were not required to be reset. Moreover, a random load perturbation was exposed to attain enhanced performance. The supreme important contributor for the load disturbances of power generations are wind and diesel sources and measured as final contributing sources to meet the peak load for improvement of dynamics of power system.

Haji & Monje revealed the firefly algorithms(FA) rate of convergence and reduced fitness function for improving them with the use of dynamic control mechanism [8]. The step size, scaling factor, attractiveness coefficient, absorption coefficient and the population size with comprehensive evolution process were selected with its best combinations for acquiring better performance using dynamic firefly algorithm (DFA). In order to improve the chopper-fed direct current motor drive performance, a fractional order PID controller related to DFA was suggested. Thus the speed control loop used the proposed controller to enhance the response. An efficiency was established by likening its performance with conventional FA, artificial bee colony algorithm, particle swarm optimization.

C. Online self-tuning PID controller

Chopra, Singha & Dewan, described tuning a PID controller was deemed a critical task. The conventional methods for tuning a PID controller have certain limitations [14]. Most of the limitations of PID controllers can be overcome via tuning the PID controller by implementing intelligent techniques. An intelligent method based on the fuzzy logic, artificial neural network (ANN), adaptive neuro fuzzy inference system (ANFIS) and genetic algorithms (GA) for tuning a PID controller. Such a controller tuned by the provided methods has been implemented for concentration control of a continuous stirred tank reactor (CSTR). The intelligent methods offer better performance in terms of varied performance specifications than the conventional Zeigler Nicholas method whereas the steady state error remains the same at zero. However, the intelligent methods required deliberate consideration for tuning the PID controllers which was considered as a major limitation of this method. Devikumari & Vijayan clarified a PID controller – which is an efficient method for the engineering applications especially in control applications[5]. The power system stability (PSS)was enhanced using PID controller along with PSS. A manual tuning was done for most of the PID controller shared with PSS and kept constant for definite operating circumstance. Generally, power system is nonlinear and the traditional methods had only lesser strength. Furthermore, it was required to simplify the problem through using most efficient optimization method.

The optimization methods were reviewed broadly. Some of the conventional methods are Soft Computing, Genetic Algorithm, Evolutionary Programming, Differential Evolution (DE) and Swarm Intelligence methods which was applicable for the effective tuning of PID gains and PSS constraints effectively. From these algorithms, soft computing and population based algorithms had some of the drawback for the design of controllers. To overcome this drawback, swarm intelligence techniques were used which would enhance the small signal stability and transient stability in power system. Abdelkarim, Mohamed, El-Garhy, & Dorrah presented an framework of applying ant lion optimizer (ALO) to found the elements of superior governor loop of thermal producers for automatic generation control (AGC) of both inter linked power system [1].

ALO regulator was employed to the test design of both thermal elements which was connected with delicate tie line of constricted capability for AGC. Eigen values were analyzed to test the effective of the technique and the results were analyzed by traditional works. The damping was obtained from ALO generator and it was positive. The drawback of the work was, the system required to develop with different renewable energy power sources. Albagul, Saad and Abujeela proposes that the conventional controllers like PI controller and PI fuzzy logic controller (PIFL) were developed to control the linear Continuous Stirred Tank Reactor (CSTR) concentration and to cut down the resolving time, stable error, overshoot percentage, and the increasing time [2]. These two controllers were of popular in industries.

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Table 1 Comprehensive Review of optimized PID

List.ref	Techniques	System	Category	Method Description	Advantages
Singh, Kuchhal, Choudhury& Gehlot[21]	deep learning neural network model predictive controller (DLNNMPC)	non-linear continuous stirred tank reactor	Optimized deep learning neural network predictive controller for continuous stirred tank reactor	CSTR performed both series and parallel reactions of progressing the training of deep learning neural network with its weight that were tuned	Effective control design
Owa, Sharma & Sutton[17]	real time nonlinear model predictive controller (NMPC)	MIMO system	real time nonlinear model predictive controller (NMPC) for a multi-variable coupled tank system	initial training of the network was carried out by utilizing a fast stochastic wavelet gradient algorithm	Trapping problem was left out
Gupta, Kumar, Rana & Mishra[7]	brain emotional learning based intelligent controller (BELBIC)	brain emotional learning	Particle swarm optimization	developed the parameterization techniques for decoupling and control system which was ensured the robust control behavior	Robustness is high
Lucky, Kumar, Chauhan & Sharma[12]	Human dynamic technique by the opinion algorithm	CSTR system	Optimal Design of PID Controller (Human optimization opinion algorithm)	PID was tuned and specifications are transformed as optimal value the isothermal concentration is maintained	Less error, Better control response by this human opinion algorithm
Wang, Gao & Qiu[23]	adaptive neural network control	CSTR system	nonlinear model predictive control method PID Controller	Inputs and the outputs of the subsystems at the device layer was sampled at the operation layer with the sampling period of Tuwhich helped to form the index prediction	delay and the dropouts of packets gets compensated andsystem stability was high

To provide a better state responses and transient responses it tried to check the output that was measured with the desired output as possible. For the unstable reactor, PI and PIFL controller have been included to control the concentration of linear CSTR and the results were obtained by the MATLAB SIMULINK by comparing PIFL and PI controller. The benefit of the reactor system with PIFL controller was demonstrated. Most essential criteria for this system was to have zero overshoot and stable state error was supposed to be none. On comparing this two controller simulation results the PIFL controller suits this criterion. Thus it was selected as the best controller than PI controller. The important benefit of this controller was that it can achieve a zero stable state error in reduced time.

Pillay & Govender present a novel approach for assessing the performance of proportional-integral-derivative (PID) controllers which were operated with the presence of non-linearity of the operation [18]. The key objective of this work was to evaluate the performance quality of controller in real time when exposed to the variations in the set point. By utilizing the given operating sections, the settings of the optimal PID controller were produced off-line through numerical optimization from a trained artificial neural network (ANN). To the effectiveness of the proposed controller bench marking scheme was demonstrated by applying the procedure is applied to a simulation model, in addition with a real process control loop which could be operated in a full scale pH neutralization plant.

The NNARMAX model was represented for choosing an optimally tuned gain scheduler controller as a realistic benchmark for a comprehensive class of nonlinear dynamic systems. By utilizing the input and output data the ANN models of pretended and created the real process systems. The inadequate data may cause a poor estimation of the model which rely on a process model. This would be affected the Nonlinear controller performance assessment (NLCPA) negatively. Thus it was significant for identifying the model more accurately for determining the optimal PID controller settings. The experimental results indicated that the proposed method was appropriate for servo tracking in nonlinear control loops like in the industries of pulp and paper, and water purification. Kaur & Brar clarified the effective optimization technique known as the human dynamic optimization (HU) model which has better effective manner of optimization as others not having such an effective method [10].

Thus the optimization of the system was considered to be of important in process control studies. Comparison of various factors yields a noticeable improvement. On applying this choice on the process control, effectiveness could be improved. Tuning should be controlled which was the major impact that relies on operation of the plant system. From this the differentiation between the PSO-PID and HU-PID controller were estimated and the outcomes represents the good show case of the HU-PID algorithm which was actually a straight forward one. Thus the effectiveness and accuracy of the system was revealed to be better when compared to the administration of the other techniques and formulations of the existing algorithms which uses the optimization technique. Among these types of algorithm which was also an effective type and could be stated as ant colony algorithm, bacterial foraging algorithm and so on. Correlation factors were also employed in this method of using the optimization technique.

Human dynamic optimization algorithm shows the better outcome rather than that of the other existing algorithm.

Zribi, Chtourou, & Djemel elucidate the control scheme where the plant weights are attuned of-line. In this scheme for the online adjustment the fixed weight was only used as controller gains [24]. The nonlinear process of PID controller was suggested here. It acquired gain over the computational time and modest structure. This study offered high racking performance by utilizing enhanced gradient decent process for the parameter changes with the use of marginal stability whereas the strength was also concerned with external disturbances. Thus the effective approach was analyzed with the simulation results of all the methods. The system was well recognized with feed forward neural network to acquire the neural network model plant and also the weights were trained using back-propagation algorithm. The gains in the controller attuned at each cycle of control where the weights of the cost function and network model (NM) are fixed. The stability of the closed loop system was assured for creating the fast learning algorithms. Based on the weight, the stability possessions were examined. The current weight update across the impact of past iteration was incorporated with the help of momentum. An impact of momentum was reliant on constancy properties of closed loop system. Thus the novel PID controller was the best approach when compared to other methods. Mittal, Raghu, & Sharma clarified an optimized technique for controlling the temperature of the heat exchanger[16]. The purpose of this work is to attain the optimum solution using hybrid controller. The temperature was controlled of about the set point even with external disturbances. The drawbacks of the existing methods were improved with this proposed method having an improved overshoot and settling time from the classical controller.

3. CONCLUSION

PID Controller tuning plays an important role to obtain the better outcome using different optimization algorithm. In this optimization based control techniques, controller tuning becomes a most significant part. PSO algorithm is used for selecting the best fitness function and monitoring the parameter variations continuously across the controller. In this survey, several existing methodologies are analyzed for the detection of self-tuning in the PID controller with different optimization technique. Similarly, several issues and the different approaches are studied. At last, different optimization algorithms are surveyed with its own advantages and disadvantages. The existing methods are having some drawbacks like initial particle selection, weak fitness function and calculation cost and more generation time. From this study, traditional methodologies limitations that could be overcome by using PSO based online self-tuning controller.

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