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Evolutionary Algorithms for the Design of Optimal Controller - A Review

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ABSTRACT

Control systems appear practically everywhere in our homes, in industry, in communications, information technologies, etc. Increasing problems with process nonlinearity's, operating constraints, time delay, uncertainty etc. have led to development of more sophisticated control strategies. So there is always a continuous search for a better technique, which can consider all such problems and provide stability to the system. Artificial Intelligence (AI) based techniques are the new entry in field of controller tuning. AI based techniques have proved their capabilities in various fields and so these are considered to give a new pace to controller tuning search technique. This paper presents a state of art literature review on the improved performance of control systems like problems from process control, electrical engineering or electromechanical systems when soft computing algorithms are applied for tuning.
Keywords : Control Systems, Optimal Control, Soft Computing, Genetic Algorithm, Evolutionary Algorithms, Particle Swarm Optimization.

I. INTRODUCTION

The natural phenomenon of homeostasis led to the foundation of the concept go feedback in control system engineering. In the 19th and 20th century, feedback led to the foundation of automatic control and has been widely applied in various applications like telecommunication, transmission & distribution of electricity, defence, process industries, etc [1]. During this period several classical control theories have been established and put into work. The control engineering dominates the industries and indirectly drives the world economy. The production of quality products is directly effected by the quality of control systems. So the design of proper and optimal control system becomes essential. There exist several optimal control theories in the literature like LQR, etc., but are not widely accepted in the industry. So, there is a need of design of optimal control systems that follows the industrial standards and offer an optimal response.

PID (Proportional Integral Derivative) controller is fixed structure controller. PID controllers alone accounts for the 90% of the total controllers used in the industries nowadays [2]. Ziegler Nichols is one of the established method for the tuning of these controllers. And there are several other established methods for the tuning of PID controllers like Cohen-Coon, CHR, etc. But the response offered by such classical methods of tuning is not always optimal, as the design objectives in control systems are conflicting in nature, improving one objective leads to the degradation of the other. So, there is a need of such robust tuning methods such that an optimal reposes is obtained.

Nature inspired Algorithms are nowadays finding a great application in engineering problems, whether they be from process control to electrical engineering, circuit design to metallurgy, etc. In control system engineering the application of nature inspired algorithms is unparalleled. They have been widely accepted and applied both in academia and industries. This paper sheds light on the state-of-art literature on the application of evolutionary algorithms in control system engineering.

II. METHODS AND MATERIAL

Evolutionary Algorithms

Evolutionary algorithms (EA's) are the set of meta-heuristic algorithms, and are inspired by the natural

phenomenon of evolution and the operators like selection, mutation, reproduction , etc., are used for the generation of new generations. EA's operate on the Darwin's theory of Survival of the Fittest, any member of the population that doesn't adepts to the process of evolution will not survive in the forthcoming generations [3]. This principle lays the foundation of the core of the EA's, and there are several established evolutionary algorithms that exist nowadays like Genetic Algorithms (GA), Differential Evolution, etc. These EAs are now being widely used in several diverse applications like art, basic sciences, engineering, economics, finance, marketing, etc.

III. RESULTS AND DISCUSSION

Design of Optimal Control Systems using EA's

In the control system design process, there is always a need for finding an optimal solution that offers best response, meeting all the design requirement and constraints. As the design objectives in control system design are conflicting in nature, it is very difficult to achieve one objective without degrading the other one [4]. Classical control theories fail to offer an optimal response that satisfy the design requirements.

So, the use of evolutionary algorithms comes handy in this case, the design objectives are minimised and an optimal controller is obtained that satisfy the design requirements. Evolutionary algorithms are one of the global optimisation algorithms and are able to easily handle such non-convex controller design problems. The use of evolutionary algorithms for controller tuning has been addressed in several diverse applications like process control, electrical systems, mechatronics, etc.

3.1 Controller Tuning using EA's in Electrical Systems

Evolutionary algorithms have been widely used in the optimal controller design of electrical systems. In [5, 6], design of PID controller has been presented for the optimal position control of DC motor using genetic algorithm. In [7], design of optimal hybrid intelligent controller using BF-GA optimization has been presented for an automatic voltage regulator system. Hailing Hu [8] presented the use of particle swarm optimization for the optimal controller design for a permanent magnet stepper motor. Ali et al. [9] presented the use of bacteria foraging algorithm for the optimal operation of a load frequency control for an interconnected system.

M. Neath et al. [10] used multi-objective genetic algorithm for the optimal PID controller design for a bidirectional inductive power transfer system. In [11], a Modified genetic algorithm approach has been presented for the design of an optimal PID controller for AC–DC transmission systems. In [12], optimal operation of the DC-DC convertors has been ensured using GA tuned PID controllers. Jaen-Cuellaret al.[13] presented optimal performance of servo systems has been achieved using GA tuned PID controllers. S. Panda et al., [14] presented the use of multi-objective genetic algorithm (nsGA-II) for the PID controller tuning for a FACTS-based damping stabiliser. In [15], differential evolution has been applied for the optimal controller tuning to load frequency control of multi-source power system.

From the above papers, we can see that the design of controllers for electrical systems using evolutionary algorithm holds a huge potential. So their use can be explored for several electrical engineering applications.

3.2 Controller Tuning using EA's in Electro-Mechanical Systems

Optimal control of electro-mechanical systems holds a huge potential for the design of such systems, as such systems demand high precision control and their applications are very sensitive. In [16], an optimal PID controller has been designed for a electro-hydraulic servo control system using genetic algorithms. In [17], Krohlinget al. designed PI/PID controllers for a motion control system based on genetic algorithms. In [18], Kasemi, designed Fuzzy-PID controller for semi-active vibration control using magneto-rheological fluid damper.

In [19], tuning of PID controller based on a multi-objective genetic algorithm applied to a robotic manipulator. In [20], Ferretti, et al. applied impedance control for elastic joints industrial manipulators. In [21], Nagarajan, et al. used GA for the state transition, balancing, station keeping, and yaw control for a dynamically stable single spherical wheel mobile robot. In [22], GA based PID controller has been applied for the magnetic bearings. In [23], optimal control of a robotic arm has been proposed using genetic algorithm

and simulated annealing tuned PID controllers. Siddiqueet al. [24] introduced a GA-based neuro-fuzzy controller for flexible-link manipulator. In [25], genetic algorithm has been applied for the optimal tuning of PID controller for a quarter car suspension system.

So, electro-mechanical systems demands high precision and their applications being in the field of manufacturing and surgery demands high level of accuracy. So, the use of evolutionary algorithms for the tuning of such electro-mechanical systems offers better performance and robustness as compared to standard/classical control theories.

3.3 Controller Tuning using EA's in Process Control Systems

In process control systems, the use of nature inspired algorithms is unparalleled, whether it may be from finding the optimal values of the process design parameters, or optimising the control of such systems. In process control, generally the regulation of the liquid flow, maintain the level of the tank at a certain level, etc., are considered.

The application of evolutionary algorithms in the design of control systems has been d widely explored. In [26], multi-objective optimization based design of PID controllers has been considered for temperature control in centrifugal machines using genetic algorithm. In [27], colonial competitive algorithm has been used for the tuning of the PID controller design in MIMO distillation column process.In [28], Kim et al. introduced a new genetic algorithm for the auto-tuning of PID controller for a reverse osmosis process. In [29] Kumaret al. used genetic algorithm based PID controller tuning for a model bioreactor. In [30], GA based ANFIS temperature controller for plastic extrusion system has been designed.

In [31], MIMO PIID has been designed for a distillation column process using colonial competitive algorithm. In [32, 33, 34], design of PID, FOPID controller for coupled tank liquid level control systems has been considered using several tuning algorithms like GA, Bat algorithm, etc. In [35], design of optimal PID controller for centrifugal temperature control system in sugar industry using genetic algorithm has been considered. In [36], Aziz et al. compared the performance of different types of controllers in tracking optimal temperature profiles in batch reactors. In [37], Rajarathinam et al. used GA for tuning the PID controller for a multivariable glass furnace process. Zhaoet al. [38] used GA for tuning a fuzzy PID control for trajectory tracking of robot arm. In [39], teaching learning based optimization algorithm for automatic generation control of power system using 2-DOF PID controller has been done. In [40], Xiao et al.introduced a self-adaptive shuffled frog leaping algorithm for multivariable PID controller's optimal tuning.

IV. CONCLUSION

The control system drives the economy of a country, as the quality of control directly effects the quality of products and the safety of process. Thus the design of optimal controllers become crucial for highly precise applications. In control system design the design of the controller spans around several design requirements and constraints. These design requirements are generally conflicting in nature and classical control theorises not always offer the desired optimal response. Evolutionary algorithms are global optimization algorithms and are suitable for solving such non-convex applications like controller tuning. The minimisation of appropriate cost function using EA's offers the global optimal controller gains. The cost functions can be either from time domain or frequency domain based upon the design requirements. The above literature signifies the use of evolutionary algorithms for the control system design and has been widely accepted in several applications like process control, electrical systems, mechatronic systems, etc. Thus the designed control system using EA's will offer an optimal response satisfying the design requirements and constraints; and thus be able to assure systems's safety as well as maintaining the desired performance.

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