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# Model Reference Adaptive Controller using MOPSO for a Non-Linear Boiler-Turbine

**G. Suganya, L. Jenifer Amla, S. P. Dwarakesh**

***Abstract - Biologically inspired algorithms are attracting lot of researchers in recent decades. Particle swarm optimization is a recent algorithm based on the movement and intelligence of swarms. This paper proposes an application of Multi Objective Particle Swarm Optimization (MOPSO) for tuning the Model Reference Adaptive Controller (MRAC) for a non-linear Boiler-Turbine system. The Boiler-turbine system is a Multi Input Multi Output (MIMO) system which is non-linear in nature and hence MOPSO is used to obtain the solution. This paper proposes a new approach combining a priority based lexicography method and the overall error for tuning the parameters of swarm in order to get the best optimal solution. The model was developed using MATLAB simulink tool and the results were compared.***

**Keywords:** ***Boiler-Turbine system, MOPSO, MRAC ,Overall error.***

## I. INTRODUCTION

The generator in thermal electric power plant generates power by rotation using high pressure steam produced by the Boiler-Turbine system. To maintain the balance in the electrical power, the pressure and water level in the drum of the Boiler-Turbine system needs to be controlled. The Boiler-Turbine system is modeled as a MIMO nonlinear system to design a controller [1]. To handle the severe non-linearity of the boiler-turbine system, several approaches were handled in the literature. Dynamic matrix control was applied to fossil power plant [2]. Hybrid controller uses conventional PID along with neural network to control the boiler [3]. Online self organizing fuzzy controllers are used for MIMO boiler-turbine system [4]. Robust control method was applied for a power plant [5]. Output tracking control was implemented to guarantee the robustness against the non-linear system [6]. LQR genetic algorithm is used to enhance the wide range performance of PI controller [7]. Extended version of dynamic matrix control was also applied to the boiler-turbine system [8][9]. The parameter of the boiler turbine system is tuned using MRAC [10]. Extended state observer is used to design the controller [11]. Handling the multi objective functions by use of MOPSO is illustrated [12]. In this paper, MOPSO-lexicography is applied with overall error for tuning the parameters of MRAC. The mathematical modeling of a non-linear boiler turbine system is used from ready reference [1] and the MOPSO is implemented. The remaining section of the paper is organized as follows. Section 2 depicts the model of the boiler turbine system. Section 3 and section 4 discusses about the methodology and its related algorithms to optimize the multi-objective functions. Section 5 depicts the MRAC design for the boiler turbine system and section 6 consolidates the simulation and the synthesis results. The conclusions are drawn in section 7.

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## II. BOILER-TURBINE SYSTEM

The boiler-turbine unit is highly nonlinear, multivariable and strongly coupled complex system. The mathematical model of this work is one of the standard non-linear boiler-turbine models proposed by Bell and Astrom [1]. This is typical oil fired, drum type boiler. The specifications of the parameters of the standard model are listed in Table 1.

**Table 1: Parameter Specifications of the Boiler-Turbine System**

| Parameter | Specification |
|---|---|
| Rated Power | 160MW |
| Drum steam Pressure | 140 kg/cm$^2$ |
| Super heater steam Temperature | 535°C |
| Volume of drum | 40m$^3$ |
| Feed water Temperature | 300°C |

The dynamics of the system introduced by Bell and Astrom is given as follows:

$$x_1' = -0.0018\, x_1^{9/8}\, u_2 + 0.9u_1 - 0.15u_3$$
$$x_2' = \left[(0.73u_2 - 0.16)x_1^{\frac{9}{8}} - x_2\right]/10 \quad (1)$$
$$x_3' = [141u_3 - (1.1u_2 - 0.19)x_1]/85$$
$$y_1 = x_1$$
$$y_2 = x_2 \quad (2)$$
$$y_3 = 0.05(0.13073x_3 + 100a_{cs} + \frac{q_e}{9} - 67.975)$$

where the variables $x_1$, $x_2$, $x_3$ denotes drum pressure (kg/cm$^2$, electric output (MW) and fluid density (kg/m$^3$) respectively [1]. The inputs $u_1$, $u_2$ and $u_3$ are the valve positions for fuel flow, steam control and feed water flow respectively. The output $y_3$ is the drum water level (m). $a_{cs}$ and $q_e$ are steam quality and evaporation rate (kg/s) respectively and are given by:

$$a_{cs}(1 - 0.001538x_3)(0.8x_1 - 25.6)/ x_3(1.03940.0012304x_1) \quad (3)$$
$$q_e = (0.85u_2 - 0.147)x_1 + 45.59u_1 - 2.514u_1 - 2.096$$

The model was based on the basic conservation laws and the parameters are estimated from the data


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measured from the Synvendska Kraft AB plant in Malmo, Sweden. Due to limitations of the actuator, the control inputs are subjected to the following constraints:

$$-0.007 \geq \frac{du_1}{dt} \leq 0.007$$
$$-2 \geq \frac{du_2}{dt} \leq 0.02 \tag{4}$$
$$-0.05 \geq \frac{du_3}{dt} \leq 0.05$$

## III. MULTI OBJECTIVE PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a robust stochastic optimization technique based on the movement and intelligence of swarms. It applies the concept of social interaction to the problem solving. PSO is used for continuous nonlinear and discrete binary single-objective optimization functions. In single-objective optimization, the speed of convergence is higher for PSO compared to other algorithms. Due to this, PSO is particularly selected for solving multiple-objective functions [13]. The proposed technique uses PSO for optimizing MRAC. Multi objective functions are solved by PSO using different approaches.

### A. Weighted Sum Approach

In weighted sum approach, multi objective functions are converted into a single objective function and PSO is applied. This approach mainly focuses on diversity maintenance by assigning the larger weight to particles which are relatively best [13]. The weighted sum for the particles pbest is calculated as follows:

$$\sum_j \frac{f_j(x_j)}{\sum_k f_k(x_i)} f_j(p_i) \tag{5}$$

where $f_j(x_i)$ is jth fitness value of particle i. The smallest weighted sum personal best is updated in every iteration. Weighted sum approach was proposed for pbest selection and now it is used for gbest selection also.

### B. Lexicography Approach

In lexicography approach, different priorities are assigned for every objective function. Based on the priority, the objectives are optimized. The algorithm for solving MOPSO using lexicography approach for the proposed technique is as follows:

Step 1: Initialize swarm
Step 2: Evaluate the fitness of each particle of the swarm.
Step 3: Select the minimum fitness value as the best global fitness value.
Step 4: Start the iteration
Step 5: For each particle, select the current global best solution
Step 6: Update the velocity and position
Step 7: Mutation
Step 8: Find the global best fitness from the current global best and previous global best fitness values.
Step 9: Update the global best position.
Step10: Continue from step 5 until iteration count exceeds
Step 11: Optimum solution = global best position

In this algorithm, the best local fitness values are selected randomly. Taking this as reference, remaining values are compared and the best solution is found. Mutation is done to avoid searching beyond the boundary values.

### C. Pareto Approach

Pareto approaches are the best suited for finding non-dominated solution to optimization problems if the dimension is more than one. Non-dominated solution is the one which cannot be improved further with respect to one objective function, without decreasing its performance for other objective functions [13].

## IV. PROPOSED TECHNIQUE

In the priority based Lexicography approach, the objective function with a highest priority is optimized first and the solution is substituted in the next priority objective function. This process continues till all the objective functions are optimized. This approach has a drawback of introducing more error for the lowest priority objective function. This leads to decay in system performance. So the proposed work combines the priority based lexicography approach with the overall error value for tuning the controller parameters. The algorithm for calculating the overall error value of the proposed work is as follows:

Step1: Find the fitness value for individual objective function. Let the fitness values are fitness1, fitness2 and fitness3 etc..
Step 2: Error value = fitness1*fitness2*fitness3…
Step 3: Overall error value = absolute of error value

Considering the advantage of combining priority based lexicography method with overall error value the modified MOPSO algorithm was presented as follows:

Step 1: Initialize the swarm
Step 2: Evaluate the fitness of each particle of the swarm.
Step 3: Select the minimum fitness value as the best global fitness value.
Step 4: Start the iteration
Step 5: For each particle, find the individual fitness value for every objective function and calculate the overall fitness which is error value.
Step 6: Select the current local best solution based on the priority and also the overall error value for each particle
Step 7: Select the current global best solution and the local best solution using same method
Step 8: Update the velocity and position
Step 9: Mutation
Step 10: Find the global best fitness from the current global best and previous global best fitness values.
Step 11: Update the global best position.
Step12: Continue from step 5 until iteration count exceeds
Step 13: Optimum solution = global best position

## V. MRAC DESIGN

In this modern world, most of the systems are non-linear. Several methods are available to control the non-linear systems among which the adaptive control method plays a vital role. In general control system, stability and characteristics of a system can be examined by the mathematical model. Mathematical modeling of nonlinear boiler turbine system is necessary because it uses the model reference adaptive controller. In the proposed technique, the reference model is designed and compared with the plant model. The convergence is reached when the error is minimum.

### A. Reference Model

The reference model gives the desired output for a set of specified input. In a boiler-turbine system, it is necessary to maintain the drum pressure at a constant value. The pressure increases linearly upto the threshold and then remains constant. So the system parameters remain at the same value upto the threshold (1). After saturation, parameters are defined by the user. At this condition:

$$x'_{m1} = 0 \tag{5}$$

Because of this, electrical output also reaches the constant value which is mathematically represented as:

$$x'_{m2} = 0 \tag{6}$$

Same as above the steam fluid density after saturation is:

$$x'_{m3} = 0 \tag{7}$$

Thus the mathematical model for reference model is designed using equations (1)-(3) and (5)-(7).

### B. MRAC using MOPSO

The proposed block diagram of MRAC for Boiler-Turbine system is shown in Fig 1. The reference model gives the desired output which is the set point for the boiler turbine system and the plant model gives the actual output of the plant. The MRAC controls the plant output which needs continuous updation of controller parameters at every time instant. Two different approaches are conventionally used to update the controller parameters ie; gradient descent approach and Lyapunov's direct approach. The existing approaches do not fully consider the presence of non-linearity in the system. So MOPSO is used to optimize the parameters of MRAC. Depending on the output and the error of the system, the specific parameters for the MRAC can be updated in the controller block. So the error minimizes and the plant reaches the desired set point.

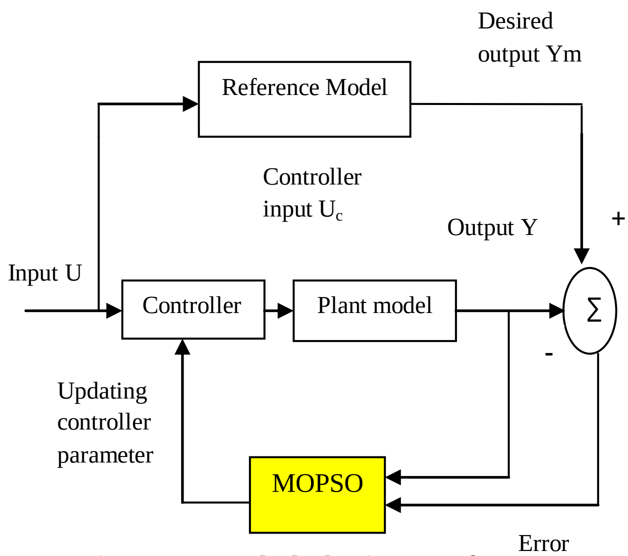


**Fig. 1: Proposed Block Diagram of M**

## VI. SIMULATION RESULTS

Two different approaches are handled in the proposed technique to optimize the MRAC viz., lexicography based approach and the priority based lexicography approach combined with overall error. From the simulation results, it is observed that the proposed technique is the best suited to this kind of non-linear problem compared to lexicography approach. The control system and process model are developed using MATLAB Simulink tool in a personal-computer environment. Sampling time for simulation is 0.5 s. The system is in steady state with initial conditions X = (87, 31,485), Y = (87, 31, 0), U = (0.5, 0.5, 0.5). Fig 2 shows the plot of Pressure vs. time for reference model and plant model with MRAC tuned using lexicographic approach and proposed approach. The result shows that, the proposed technique responds at a faster rate and the change in plant output error decreases even with an existence of nonlinearity. Fig 3 shows the plot of Electrical Output vs. time for reference model and plant model with proposed MRAC tuned using the two approaches. This algorithm decreases the error of electrical output compared to lexicographic method. The electrical output depends on the steam pressure so that the lower error in pressure results in the decrease of electrical output error. Fig 4 shows the plot of steam flow density vs. time for reference model and plant model with MRAC tuned using lexicographic approach and proposed approach.

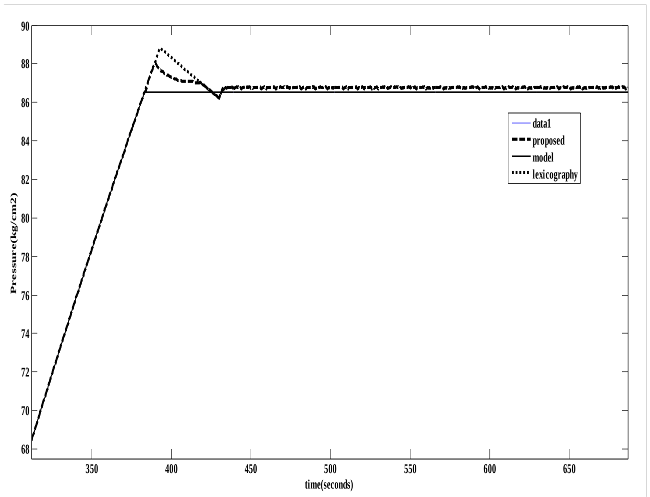


**Fig. 2: Boiler Pressure for Reference Model and Plant Model with MRAC Tuned by Lexicography and Proposed Method**

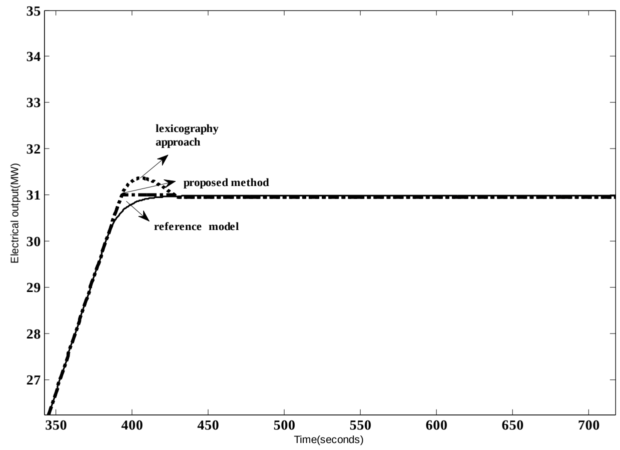


**Fig. 3: Electrical Output for Reference Model and Plant Model with MRAC Tuned by Lexicography and Proposed Method**


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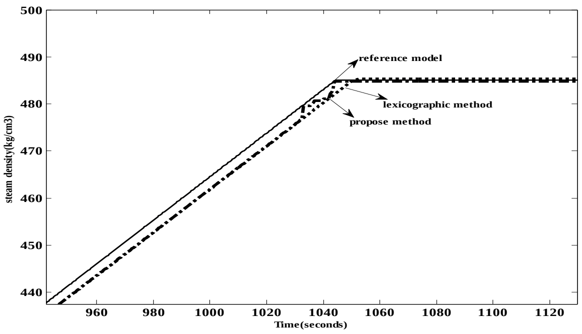


**Fig. 4: Steam Flow Density in Reference Model and Plant Model with MRAC Tuned by Lexicography and Proposed Method**

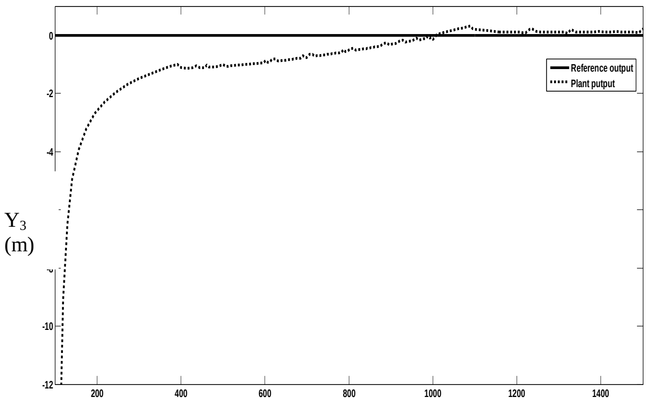


**Fig. 5: Drum Water Level in Reference Model and Plant Model with MRAC**

The drum water level Time(s) ler-turbine system reaches set point when the steam flow density reaches the set point. The inputs which are given to the plant for two approaches get desired outputs are shown in Fig 6 and Fig 7 respectively.

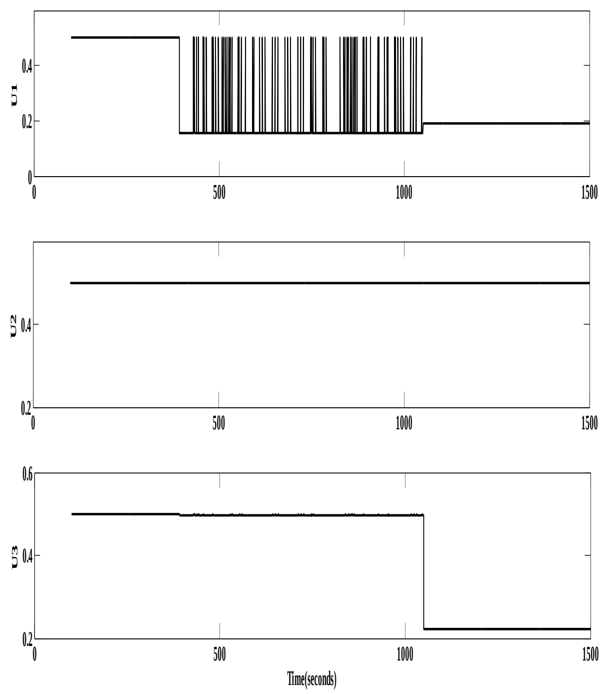


**Fig. 6: Inputs given to the Plant to get Desired Set Point in Lexicographic Method**

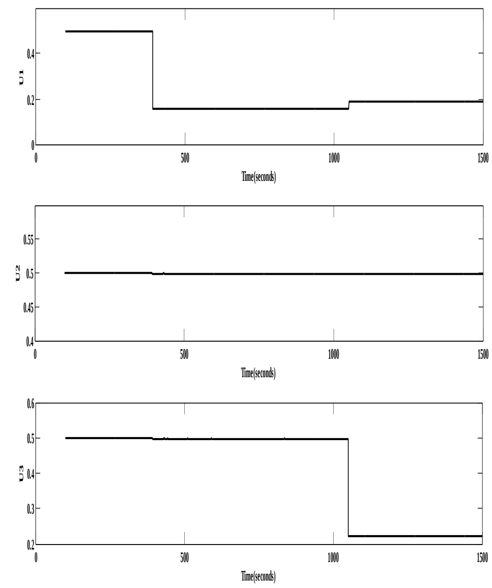


**Fig. 7: Inputs given to the Plant to get Desired Set Point in Proposed Algorithm**

## VII. CONCLUSION

This paper proposed a design of MRAC using evolutionary computation technique PSO and its application in Boiler-Turbine system. In this proposed method, four objective functions are taken to obtain the controller parameters of the MRAC. They are updated based on the output conditions at present instance. The simulation results show that the proposed controller is suitable for the control of Boiler-Turbine system than the lexicographic algorithm based tuning. Results are validated using standard input output condition.

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