# A Hybrid Technique for the Performance Optimization in the Combustion Process of a Power Plant Boiler: An Efficient ANNSSA Technique

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## Abstract

In this paper presents a hybrid method for optimization process of combustion in power plant boiler. ANSSA scheme will be joint implementation of Artificial Neural Network (ANN) as well as Salp Swarm Optimization Algorithm (SSA) known ANNSSA. Here, ANN training process will be enhanced by using the SSA calculating. The optimization of economic parameters reduces excess air level and performs combustion efficiency at boiler system. Due to the operation of service boiler, oxygen content of flue gases is one of the significant factors which influence the efficiency of boiler, and influence each other to other thermal parameters of economic like temperature of flue gases combustion, unburned carbon at fly ash slag and consumption of coal power supply. The combustion performance denotes a

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saving at operating costs of boiler. ANNSSA method evolved for process of combustion to enhance the implementation and efficiency of the power plant boiler. At that time, ANNSSA technique is implemented at MATLAB/Simulink work platform as well as implementation is evaluated using existing techniques.

**Keywords:** Artificial neural network, Salp swarm optimization, air to fuel ratio, Boiler combustion system.

## 1 Introduction

The continuous increase in world population as well as technological developments leads to an increase at consumption of electricity. Due to data EIA (Energy Information Administration), from 2000 to 2012, production of world electricity maximized 6.46%. In normal, electricity is originated to fossil fuels burning or renewable energy utilizing [1]. Although power plants of renewable energy (wind, solar, hydroelectric, geothermal, tidal) have undergone strong improvement at last decade, fossil fuel power plant remains major supplier of electricity at several countries. To approximate 85% of energy can supply to fossil fuels till 2030 [2]. Today, coal is the major form of fossil fuel power plant. Recently, the growing demand for protection of environmental, energy conservation as well as reduction of pollutant, conservation energy of coal-fired power plants that is main department of energy consumption, is significant [3].

The boiler is one of the major equipment of coal power plant. It is mainly utilized at business activities, like power plants for purpose of processing [4]. Based on heat and electricity, boiler consists of significant role as part that constructs steam. The heat of steam formation is generated by heat as a outcome of combustion process at area of boiler [5]. The furnace gas and fuel are comprised and burned, obtain heat and flue gases on the boiler portion of the elevator [6]. The mixture of steam as well as water will pass to steam drum and transfers with another area of steam boilers [7]. Therefore, several older-design utilities emit more NOx pollutants to boiler limit (300 MW) and can be hazardous to the environment [8]. As gas emissions around the world become more stringent, coal-fired power plants face significant challenges regarding techniques as well as technologies to satisfy these novel requirements of environment [9]. Moreover, the evolution of plant as well as flue gas cleaner, controlling the operating conditions of boiler is significant and cost-effective steps to influence emissions of NOx. The problem of controlling and optimizing of boiler production process to perform the efficiency of boiler has been widely studied worldwide [10, 11].

Recently, it has been show that combustion optimization is an effectual way to reach low combustion of NOx at coal utility boilers, that low emissions of NOx reach to establishing the operating parameter of boiler utilizing artificial intelligence, like neural network, expert system, fuzzy logic as well as algorithm of genetic. But these techniques are hard to establish and prefer a proper model that predicts emissions of NOx [12, 13]. Artificial neural networks are efficient tools between artificial intelligence methods that may regenerate the relationships among input as well as output variables of nonlinear systems [14]. It consists of many investigation papers which focus on application of neural networks to modeling emissions of pollutant. Therefore, neural network suffers a weakness that consists of numerous control parameters require, hard at maintaining balance solution as well as danger of excessive adjustment [15]. Nowadays, support vector regression (SVR) has been victorious at mapping hard as well as nonlinear high relationship among input and output system. Based on authors' knowledge, SVR has never implemented with emissions of NOx model of coal boilers [16]. To avoid the inconveniences, few optimization algorithms used to manipulate the model inputs in order to minimize emission output [17]. Evolutionary algorithms (EA) are optimized methods that imitate biological systems that are allocated as research category known life of artificial. Some algorithms suggested resolving impacts of large-scale optimization that traditional methods of mathematical can fail [18]. EA consists of genetic algorithm, memetic algorithm, particle swarm optimization, ant colony systems as well as shuffled frog jumps. But these algorithms are mainly affected by some weakness [19]. Therefore, it cannot have attempted to evolve another optimization algorithm to decrease emissions of NOx [20].

In this paper presents a hybrid method for optimization at process of combustion power plant boiler. ANNSA scheme will be the joint implementation of Artificial Neural Network (ANN) as well as Salp Swarm Optimization Algorithm (SSA) called ANNSSA. Remaining paper is described as pursues: Section 2 clarifies recent research work. Section 3 clarifies overview of boiler combustion system. Section 4 depicts the hybrid optimization process of ANN. Section 5 depicts the simulation result as well as discussion. Section 6 concludes the document.

## 2 Recent Research Works: A Brief Review

Several investigation papers are obtainable at literature that depends on boiler's performance optimization at power plant using various techniques. Here a few of them are reviewed.

Gulotta et al. [21] presented a technique to analyze design optimization contributes with ecological evolution of technology. This paper evolve a concept via implementation of Construction Law, utilized depend on technology design as "evolution" (configuration, shape, structure, pattern, rhythm) as well as Life Cycle Assessment (LCA), employ to quantify the issues of environmental design options. Depend on the combination technique evaluates how the evolution of technology influence the surrounding based on its life; expand the concept of design evolution. Research was enforced with case study of active boiler of biomass. This research evaluates the fundamental case as well as series of alternative conditions adapted to Law of Construction, ensures the similar output of thermal energy. The outcomes are evaluated graphical and analytical to "general methodology of coefficient performance", which research compensations to recognize the better configuration. Moreover, LCA includes analyzing the energy as well as performance of surrounding various design alternatives, to better option capable to decrease the needed global energy of 0.33% as well as established issues of 4%. This technique was established to help decision making based on the process of optimization. Pambudi et al. [22] have implemented a research to access the performance of fluidized bed boiler at ethanol plant production via energy as well as inevitable evaluation. It allows pre-heater as well as deaerator optimization perform efficiency of system. Operational data as production of ethanol plant were possessed among 2015 and beginning 2016. It was demonstrated that total energy derived as fuel was 7783 kJ/s, though exercise efficiency of system was 26.19%, to 2214 kJ/s utilized at production of steam, though 71.55% was lost due to the irreversibility components as well as residual heat of pre-heater. The exercise efficiencies of individual system components, like boiler, deaerator as well as pre-heater, was obtain with 25.82%, 40.13% and 2,617%, rewardingly, to pre-heater consists of minimum organization. Therefore, pre-heater consists of greatest potential to perform the organization of boiler system. The pre-heater optimization displays which increase at temperature of pre-heater outlet positively influence the organization of deaerator exercise.

Zhang et al. [23] have research the out-of-design performance of double-source boiler power generation system-level modeling method. An instance of, heat as solar power tower (SPT) was denoted at 660 MW power unit of supercritical coal, as well as two combination methods were examined. Evaluation model system was suggested that combined the process of transient as heliostat field to storage of thermocline thermal energy of tank. According to the performance out-of-design like hybrid system at typical year was evaluated. The outcomes divulge the significance of seasonal variation of direct normal isolation (DNI), thermal energy storage method as well as methods of integration. Both qualities of sunlight as well as number of solar flow must affect the organization of solar energy; though maximize at volume storage must reduce organization download. Rashid et al. [24] have developed a dynamic model of hybrid natural/solar gas system utilizing integration of heat as well as intelligent control flow. Natural gas was utilized as fuel of supplementary, that improved the reliability of system as well as maximized organization of power blocking cycle via use of temperature maximized. In this paper, it consists of two energy sources (solar and natural gas) was utilized to real-time optimization (RTO). An optimizer depend on quadratic scheduling was utilized to redirect heat with generator of steam or to preheating the boiler feed water dictated by the optimizer. Based on low solar conditions, RTO directs solar heat with lower temperature heat sink (boiler feed water pre-heater) to create best utilize of solar heat. Based on large conditions of solar, solar heat flows to generator of steam (maximum temperature heat sink) as well as boiler feed water pre-heater at series. Optimization was most well organized at minimum conditions of irradiation (morning, afternoon, winter, cloudiness, and so on) since it is capable to clarify conditions which maximizes the use of solar energy.

Akbari Vakilabadi et al. [25] have suggest to recover large amount of water contained as well as heat of power plant, wastewater entering the environment was reduced s well as total power of the power plant maximized. That recovery system consists of evaporator as well as vacuum pump. At this system, a vacuum was created at vacuum tank by means of a vacuum pump that causes water to evaporate and injected with cycle of steam. The outcomes displays to adding the system of recovery, amount of wastewater drained from plant with surrounding environment decreases as 3,118 kg/s to 1,799 kg/s. Also, the outcome of Evaporator vacuum in output power as well as amount of water recovered indicates the reduction of Evaporator vacuum pressure, amount of output power was reduced, but instead based on further evaporation of water, amount of water recovered at evaporator increased. After the analysis of energy and exergy, the outcomes are optimized to Genetic Algorithm. Inlet temperature of HPT1, inlet pressure of HPT1, outlet pressure of every turbine as well as pinch point for first heat exchanger is examined as resolution variables.

### 2.1 Motivation of the Research Work

Generic review of recent research paper displays which boiler is an important key equipment of the power plant. Boilers may be used at several technical enterprises, like power plants as well as purpose of processing. Based on combined heat as well as electricity plant, boiler consists of significant key as part that gets steam. Due to the operation of service boiler, oxygen content of flue gases is one of the significant factors which influence the organization of boiler, and influences each other to other thermal parameters of economical like temperature of flue gas, combustion, unburned carbon at fly ash as well as slag and consumption of coal of power supply. Many researchers deal with this problem with different technologies in the literature like neural networks, expert system, fuzzy logic, evolutionary algorithms (EA), memetic algorithm, particle swarm optimization (PSO), ant colony systems (ACO), shuffled frog jumps as well as genetic algorithm etc. To utilize fuzzy logic controller as wind turbine/PV/hydrogen/HRES battery depend on management of energy, it provides best outcomes but does not functions the single nature theory of fuzzy systems. These algorithms may be evolved to resolve impacts of large-scale optimization, mathematical traditional methods can fault. On the contrary, it has been shown that PSO has the capability of best global search. Therefore, at PSO algorithm, velocity equation has variables of stochastic; hence better overall value varies unpredictably. Moreover, the above mentioned optimization algorithms are mostly affected by some weakness. Therefore, it has no attempt to evolve another optimization algorithm, by decrease the emissions of NOx. Also, control systems are generally designed to make sure stability system as well as rapid response and reduce NOx emissions. Very few papers depend on approaches to resolve these issues are suggested in bibliography; disadvantages as well as issues prompted this investigation paper.

## 3 Overview of Boiler Combustion System

The boiler is mainly used to heat water to obtain steam. Steam generated by boiler is utilized for various purposes such as sterilization, heating, drying and humidification and also generating power. Boiler is an enclosed pressure vessel which is used to convert the water in to steam by obtaining heat from

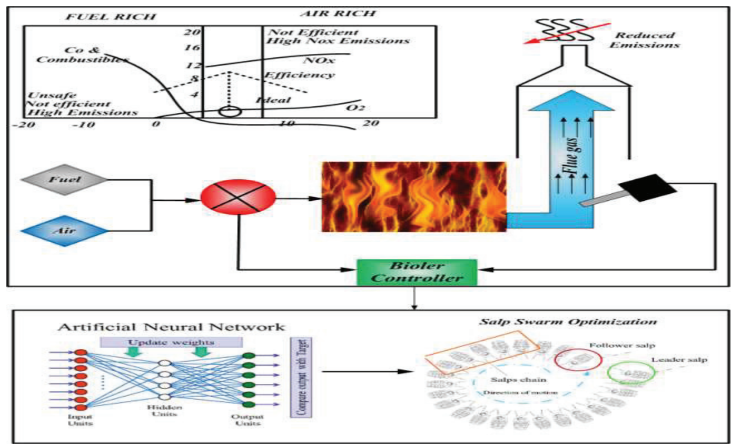


**Figure 1** Boiler combustion system using ANNSSA technique.

other source [26]. The combustion system is the process which is used for igniting and burning a fuel source and when a fuel is burned then it release energy at heat form, heat is used to transform water in to steam [27]. In boiler it has four parts they are burner, combustion chamber, heat exchanger as well as pluming apparatus.

**Burner:** The combustion reaction inside the boiler initiates burner. When the system requires obtaining heat, thermostats electronically pass a message with burner. From an outside source, fuel is forced to mechanism of filter with boiler, frequently a fuel tank adjacent. Nozzles in the burner convert this fuel at fine spray as well as explode it, take the reaction at combustion champer [28].

**Combustion Chamber:** The fuel is made of cast iron and burned at combustion chamber of boiler. At short time, temperature on combustion chamber can rise with several hundred degrees [29]. Heat originated at combustion chamber is passed with exchanger of heat system.

**Heat Exchanger:** At boiler system of hydronic, water is filtered in the chamber of combustion by series of flue [30]. Boiling water under pressure is pumped via pipes with radiators or heaters of the motherboard that provide off the heat energy generated at boiler.

**Fuel Sources:** Boilers may run at several fuels. Heating fuel, kerosene and liquid propane are usual.

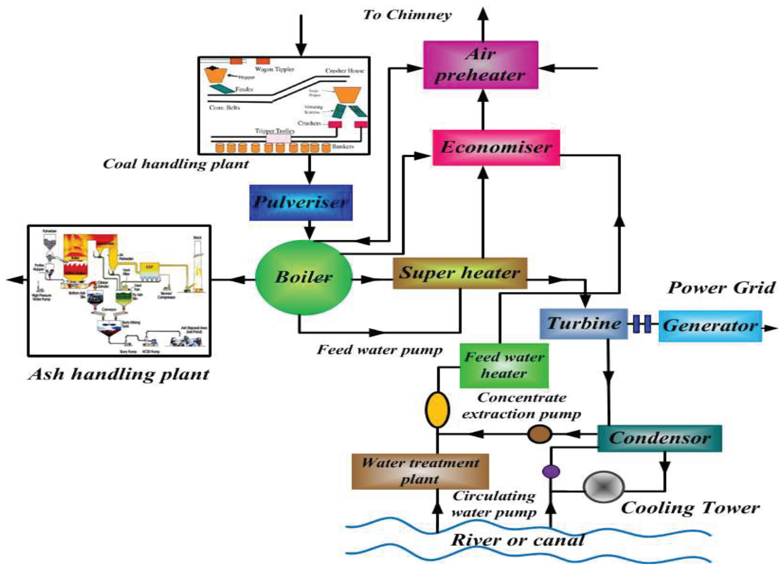


**Figure 2** Components of boiler combustion system.

### 3.1 Main Components of Boiler

The main components of boilers are given as follows (Figure 2):

1. Combustion Chamber: It is used to burn the fuel and free heat.
2. Drum: It consists of water as well as steam.
3. Water walls: It is used to heat water.
4. Super heater: It will heat up steam till it arrive the temperature as superheat.
5. Re heater: From other parts of the boiler it will reheat the steam.
6. Economizer: It is utilized to preheat water as well as it absorbs heat from flue gas.

### 3.2 Combustion Process

Combustion is the rapid oxidation of fuel at mixture of fuel and air which produces and flow large amount of heat and gas. Accomplishing the mixing of fuel and air in heavy temperature is known as combustion [31]. The additional combustion air is supplied to assure a full combustion hence each fuel molecule may simple to obtain the number of oxygen molecule to full the combustion [32].

### 3.3 Percentage of Excess Air and Oxygen

The excess air is used to furnish the total number of air combustion to fill the process of combustion. If the oxygen is not used and the boiler will leave at flue gas, then excess air is used [33]. Basic equation of excess air is given as follows:

$$Y = 100(W_a + \gamma_a W_g - W_f R_s)\frac{1}{W_f R_s} \tag{1}$$

where excess air is denoted as *Y*, air flow as $W_a$, Fresh air exhausted from the flow of gas is represented as $\gamma_a$ and the air to fuel ratio is denoted as $R_s$.

Basically the percentages of extra oxygen gas which release the boiler as flue gas demonstrate the percentage. As the excess air is already known, according to Equation (1), computation of percentage of oxygen can be changed after computation of excess air [34]. Formula for excess air depends on the percentage of oxygen represent as below:

$$Excess\ air(\%) = k\left[\frac{21}{21 - \%\ oxygen} - 1\right] \times 100 \tag{2}$$

where gas, oil as well as coal value of k represented as 0.9, 0.94 and 0.97.

### 3.4 Combustion Efficiency

In this process, with an elevated temperature, the outlet gas will leave the boiler to stack. It means that not entire heat is transferred to warm the water at part of river [35]. When a heat leaves the boiler, it is the loss, which maintain the process of combustion and indicates the temperature of flue gas. The organization of combustion is a scalable organization, which the heat generated by fuel, or heat obtained by the process of combustion, is passed with heat usable. The organization of combustion scalable is pretentious to supply of fuel, surplus air level or percentage of oxygen, utilized fuel type, combustion air as well as temperature of combustion gases.

### 3.5 Optimization of Air to Fuel Ratio

The relationship among air and number of fuel is known as air/fuel ratio (AFR). While maintain excess light air, the operation of an efficient boiler requires the continuous combination of fuel and air flows. To obtain the same AFR ratio, both air and fuel need to have the same percentage because air and fuel flow meters are reduced. Excess air level will be reduced by the proper ARF ratio. The increase of combustion efficiency was denoted to combustion improvement and leads to save the cost of boiler eventually. Due to organization of combustion, operation cost savings is affected as well as production of steam boiler.

## 4 Hybrid Optimization Process of ANN

ANN is used to developing the mathematical structures and it has the well approach for the ability to learn. It has a notable capability for deriving complicated data. Generally ANN has two steps: training as well as testing, and also it present three types of layers: input, hidden as well as output [36]. Based on input layer, data set will fed to the network and activate the hidden layers. Each layer gets their input from the left side of their neuron.

Step for the process of ANN

***Step 1:*** For learning the network the weight of the neuron is randomly assigned. The range of the interval was represented as (0,1).

***Step 2:*** The parameters of ANN are gained depend on error function minimized.

***Step 3:*** Output is determined from the neural network.

$$y_{out} = \beta + \sum_{n=1}^{N} w_{2n} y_i(n) \tag{3}$$

***Step 4:*** The activation function is demonstrated.

$$y_i(n) = \frac{1}{1 + \exp(-w_{1n} * y_i(n))} \tag{4}$$

***Step 5:*** Weight changes in the network is evaluated.

$$\Delta w = \delta \cdot y_{out \cdot BP_{error}} \tag{5}$$

### 4.1 Hybrid Technique Using SSA

SSA is the algorithm of nature-inspired and used for the purpose of evolving a population as optimizer based on behavior of salps swarm [37]. SSA described as flexible, ease and easy to understand has an iterative nature. The salp can able to update its vector locations and the leading salp will criticize

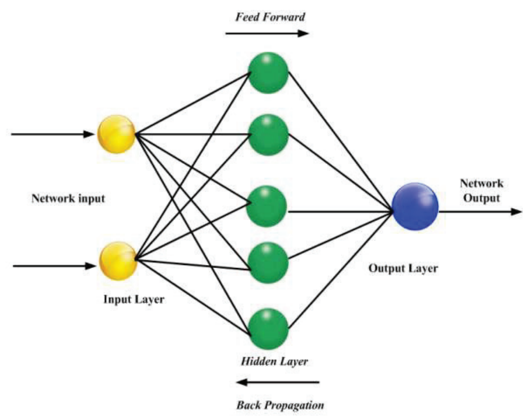


**Figure 3** Layers of ANN.

the source of food direction and the other followers will move to remaining salp.

The population of salp as $X$ consists of $N$ agents to dimensions $d$. Therefore, it may reveal to matrix $N \times d$-dimensional, as delineated.

$$xi = \begin{bmatrix} X_1^1 & X_2^1 & \dots & X_d^1 \\ X_1^2 & X_2^2 & \dots & X_d^2 \\ \vdots & \vdots & & \vdots \\ X_1^n & X_2^n & & X_d^n \end{bmatrix} \tag{6}$$

The position of leader in the SSA, is calculated in Equation (7)

$$X_j^1 = \begin{Bmatrix} f_j + C_1((Ub_j - Lb_j)C_2 + Lb_j)C_3 \geq 0.5 \\ f_j - C_1((Ub_j - Lb_j)C_2 + Lb_j)C_3 < 0.5 \end{Bmatrix} \tag{7}$$

where $X_j^1$ represents leader's location as well as $f_j$ divulge the vector position source of food at *j*th dimension, $Ub_j$ displays posterior bound of $j$th dimension, as well as $Lb_j$ denotes inferior bound of *j*th dimension, $C_2$ and $C_3$ denotes random values inside [0, 1], $C_1$ represents major parameter of algorithm denoted at Equation (8).

$$C_1 = E_2 - \left(\frac{\Delta T}{T_{Max}}\right)^2 \tag{8}$$

where *t* represents repetition, though $T_{Max}$ displays maximum number of repetitions. To maximize repetition count, parameter reduces. As outcomes,

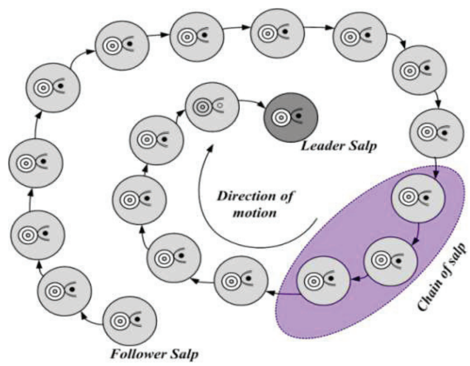


**Figure 4** Salp chain process.

it may maintain to put one or more assert at inclination diversification of initial stages as well as put more assert on intensification tendency at final steps of optimization. Location of followers is adjusted to equation.

$$X_j^i = \frac{X_j^i + X_j^{i-1}}{2} \tag{9}$$

here $i \geq 2$ and $X_j^i$ represents location of *i*th follower salp in *j*th dimension.

## Steps of SSO

***Step 1*: Initialization**
Initialize the position of salps

***Step 2*: Random Generation**
Based on the process of initialization, a random behavior of the gain parameter is generated.

***Step 3*: Fitness Function**
In fitness function, calculate fitness value of each salp

***Step 4*: Updation**
Update the initial position of leader salps, follower salps and update the best position of food source

***Step 5*: Termination**
Find the next generation until stopping criteria, if it is not satisfied goes to step 3.

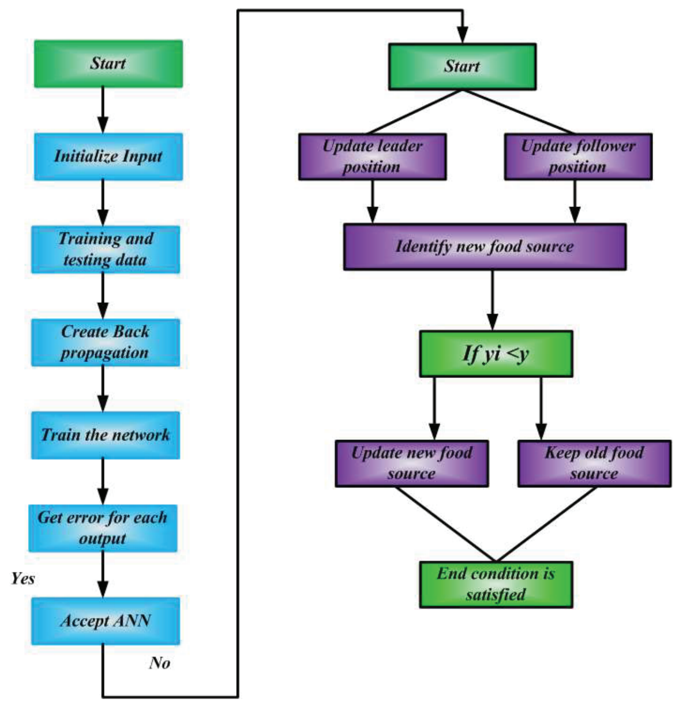


**Figure 5** Flowchart of ANNSSA.

## 5 Result and Discussion

In this section, simulation outcomes and discussion of hybrid technique for optimization at process of combustion power plant boiler is depicted. Three case studies were presented they were: no changes in air to fuel ratio, variation occurs in air to fuel ratio between 150 to 250 sec and step changes in air to fuel ratio. Here input as well as output for proposed and existing techniques is presented. Figure 6 shows the analysis of input for the air to fuel ratio. Here input of the air to fuel is remains constant and no changes occurs until the operation end. Figure 7 shows the evaluation of output for proposed air to fuel ratio. Here output of air to fuel ratio increased from 0 to 100 and remains stable until the operation end. Figure 8 shows analysis of output for proposed as well as existing technique. Here, proposed ANNSSA technique increased up to 100 as well as remains stable until the end and no variations were occurred. In the existing ANN technique it varies from the time period of 0 to 50 sec. The existing GA technique varies from the time period of 0 to 48 sec. The existing SSA technique varies from the time period of 0 to 40 sec. Compared to the existing technique, no variations were occurred in the proposed ANNSSA technique. Figure 9 shows the analysis of input for the air to fuel ratio. Here, input of the air to fuel is remains constant at the time period of 0 to 150 sec and the variation occurs between 0 to 150 sec and then it remains constant from 250 to 400 sec.

**Case 1:** No changes occur in air to fuel ratio

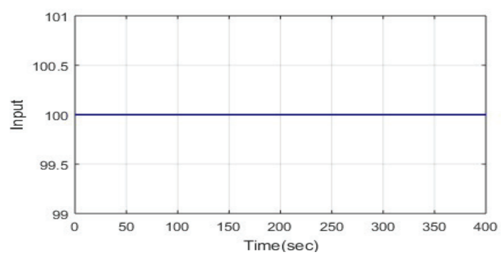


**Figure 6** Analysis of input for the air to fuel ratio.

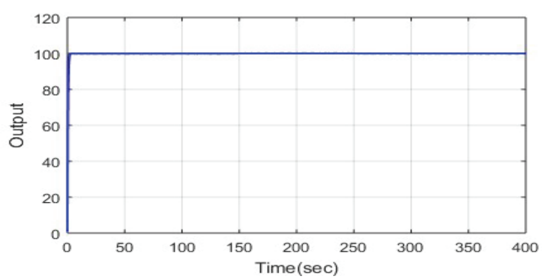


**Figure 7** Analysis of output for the proposed air to fuel ratio.

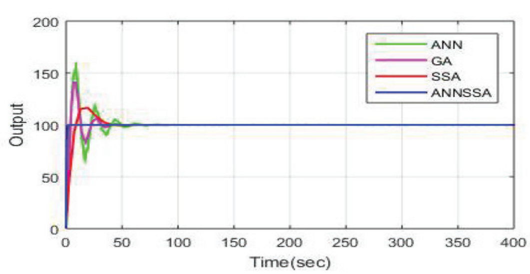


**Figure 8** Analysis of output for the proposed and existing technique.

**Case 2:** Variation occurs in air to fuel ratio between 150 to 250 sec

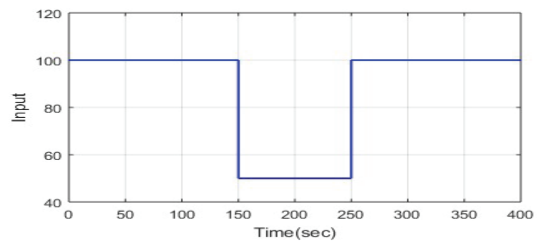


**Figure 9** Analysis of input for the air to fuel ratio.

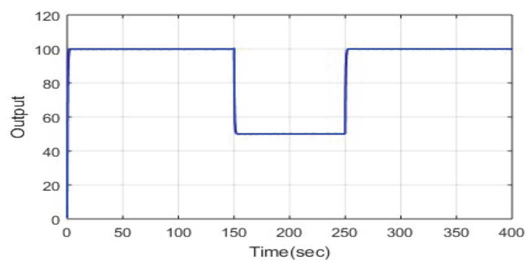


**Figure 10** Analysis of output for the proposed air to fuel ratio.

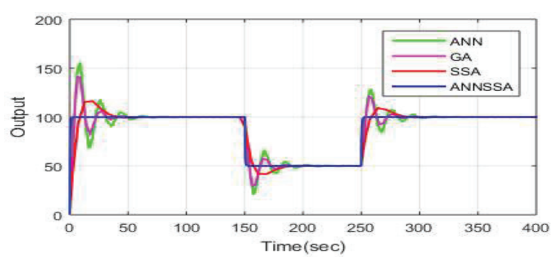


**Figure 11** Analysis of output for the proposed and existing technique.

**Case 3:** Step changes in air to fuel ratio

Figure 10 shows the analysis of output for the proposed air to fuel ratio. Here, output of air to fuel ratio increased from 0 to 100 and remains constant at the time period of 0 to 150 sec and the variation occurs from 150 to 250 sec then it remains stable until the terminal. Figure 11 shows analysis of output for the proposed and existing technique. Here the proposed ANNSSA technique increased up to 100 and remains constant at the time period of

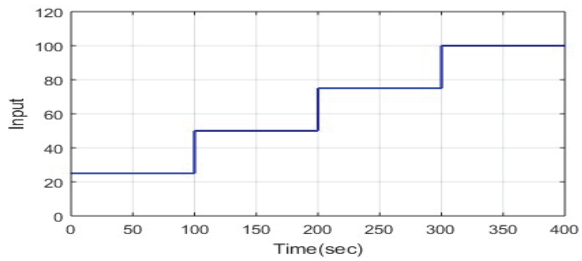


**Figure 12** Analysis of input for the air to fuel ratio.

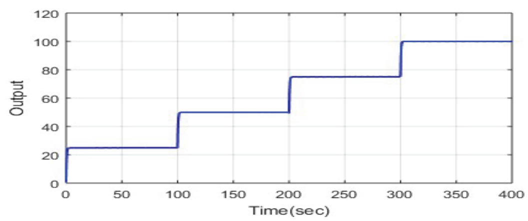


**Figure 13** Analysis of output for the proposed air to fuel ratio.

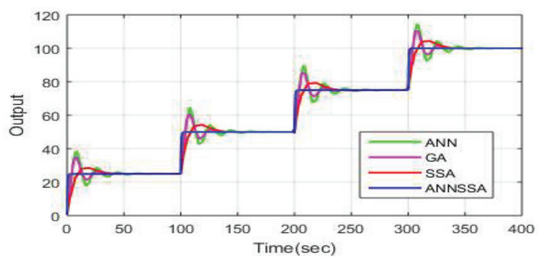


**Figure 14** Analysis of output for the proposed and existing technique.

1 to 150 sec and variations occurs at 150 to 250 sec. In the existing ANN technique it varies from the time period of 0 to 150 sec. The existing GA technique varies from the time period of 0 to 148 sec. The existing SSA technique varies from the time period of 0 to 140 sec. Figure 12 shows the analysis of input for the air to fuel ratio. Here, input of the air to fuel is increased from 25 to 100 at the time period of 0 to 400 sec. Figure 12 shows the analysis of output for the proposed air to fuel ratio. Here, input of the air to fuel is increased from 20 to 100 at the time period of 0 to 400 sec. Figure 14 shows the analysis of output for the proposed and existing technique. Here the proposed ANNSSA technique increased from 20 to 100. In the existing

ANN technique it varies from the time period of 0 to 350 sec. The existing GA technique varies from the time period of 0 to 300 sec. The existing SSA technique varies from the time period of 0 to 350 sec.

## 6 Conclusion

An efficient hybrid method for optimization at process of combustion power plant boiler based on ANNSSA scheme is presented. Here, the ANN training process enhanced by using the SSA calculation. ANNSSA method may be developed for combustion process to enhance performance as well as effectiveness of power plant boiler. Using ANNSSA technique, the boiler performance in power plant will be optimized effectively as well as the application of controller with process of combustion outcomes at important annual operational cost savings at operation of boiler. Also, the proposed technique is used to find the optimal solution with least calculation as well as decreases the complexity of algorithm.

## Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed.

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