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INTELLIGENT MODELING AND OPTIMIZATION OF BOILER DESIGN

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ABSTRACT

A closed vessel in which water or fluid is heated is called as boiler. The various requirements and efficient operation regarding the development of the complex heating system of the boiler is increased due to the availability of the technical building equipments. Furthermore, in existing buildings the heating system is often historically evolved and contains parts having different ages. Those systems have limited capacity to suit the requirements of replaced components. This paper investigates the operational behavior associated with the design of the boilers along with diverse methodologies. The categorization of the intelligent modeling methods for the boiler design is mentioned. Moreover, the features and challenges regarding the diverse intelligent methods and the description about the management of boiler design in an effective manner is also mentioned.

Keywords: Boiler, Intelligent Modelling Methods

I. INTRODUCTION

Recently, boiler plants are involved in finding its applications in energy saving technology and management for power saving and reduction of emissions. So, the circulated fluidized bed boiler (CFB) emerged as a new boiler combustion technology which has the capacity of low Nitrogen Oxide emission and increased desulfurization. The development of CFB boiler technology involves the need for increased energy saving with high capacity and parameters. To meet the demands for the development of CFB boiler technology, optimization and parameter management are necessary which will enhance in optimizing the working parameters, in turn leading to energy-saving and emission-reduction in boiler plants.

The advanced boiler plant modelling strategy includes experimental based modelling [7] [8] and first principle based modelling [9] [10]. The experimental modelling is utilized for control designing and reflecting the major nonlinear dynamics. The first principle based modelling shows the relationship between engineering principle and physics and true plant parameters and it can control the algorithm evaluation. For better boiler efficiency, innovative methods have to be developed with advanced optimization approaches. The optimization of boiler operation parameters can be achieved by two broad methodologies, namely, (a) traditional method and b) intelligent method. In traditional method, the design value, experimental value, historically optimum vale and actual data are used to optimize the boiler operational parameters. The method has advantages such as real time updating at good probability, while it has disadvantages such as difficulty in handling multi-parameters, high

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investment of manpower and resource, survey and install errors, equipment aging questions and limitations in mining strategies. The intelligent method is based on data mining technology and intelligent technologies. The data mining technologies include correlation analysis, clustering, prediction and deviation inspection. The intelligent technology includes neural network [11] [12] [13], fuzzy logic [14], pattern recognition and genetic algorithm. The advantages include strong manoeuvrability, real time updating and solving complex modelling. The disadvantages include longer running time for correlation. So, considering its drawbacks, new advanced boiler power plant modelling strategies are introduced for better optimization.

II. DESIGN METHODS AND MODELLING OF BOILERS

A. Adopted Methodologies

In 2015, Beyhan and Kavaklioglu [1] developed the modelling of U- tube steam generators (UTSG) with online and offline fuzzy system-based extreme learning machine and artificial neural network (ANN). The exogenous input topology combined with nonlinear autoregressive is used to detect the water level of UTSG system. The performances measures such as minimum-descriptive- length and root-mean-squared error are used and the performances are evaluated using the number of neurons in ANN and number of rules in fuzzy system. Although the extreme learning machines has the benefit of achieving higher degree of modeling precision, good learning ability and efficient learning, they has the property of arbitrary initialization leading to an uncertain precision. Secco et al [5] exploited the computational approach to reduce the NOx emission in a 600MW tangentially-fired pulverized coal boiler. They used Genetic algorithms that is able to generate the new boiler settings automatically. The algorithm is combined with CFD simulations of the boiler for better target function. The developed approach reduces the NOx emissions with less corrosion and operational cost. Though genetic algorithm is able to handle uncertain system characteristics, it lags under real time performance. Sayed [6] proposed a new hybrid jump PSO which is based on Gaussian and Cauchy mutation to tune the gains of PI controllers to the boiler turbine unit. The developed approach is based on the observation of local and global best particles and the simulation results shows better optimization of control parameters. Although PSO has good convergence rate, it converges to local optima and its high dependency on algorithm parameters and the nature of the search space reduces the interest among the researchers.

In 2013, Liu et al [3] have worked on modelling the boiler unit with the nature of 1000 MW and ultra supercritical property. The developed optimizing boiler model is done based on the efficiency of neural networks and the genetic algorithm. The new model works well, handles the large scale system parameters and rectifies all the drawbacks of conventional analytical techniques, but it lacks the knowledge or imprecise framing of the objective function leading to poor performance.

In 2012, Kljajic et al [4] developed a method for finding the efficiency of boiler which depends on the operating performance measurement. They used the strategy of neural networks for analyzing its efficiency and performance of randomly selected 65 boilers that are located at 50 sites in Northern Serbia. New techniques are applied for the rational study of energy. The neural network model had good learning ability but the issue of randomness arises due to the arbitrary initialization. In 2011, Hengyan et al [2] have worked on optimization of the structure of network model for predicting the efficiency of fluidized bed boiler. They used the absolute mean impact value as the performance measure for better predictive ability of the developed model and applied the

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genetic algorithm for finding the optimized value. Certain instances of the research works have also contributed to exploit the traditional controlling scheme such as PI controllers often results in poor controlling. Hence, the methodologies adopted in the current literature for efficient modeling and control of boiler design process has wide research gaps. The intelligent modelling methods developed for the design of boiler is shown in fig 1. The overall taxonomy of diverse methodologies along with its advantages and disadvantages are shown in fig. 2.

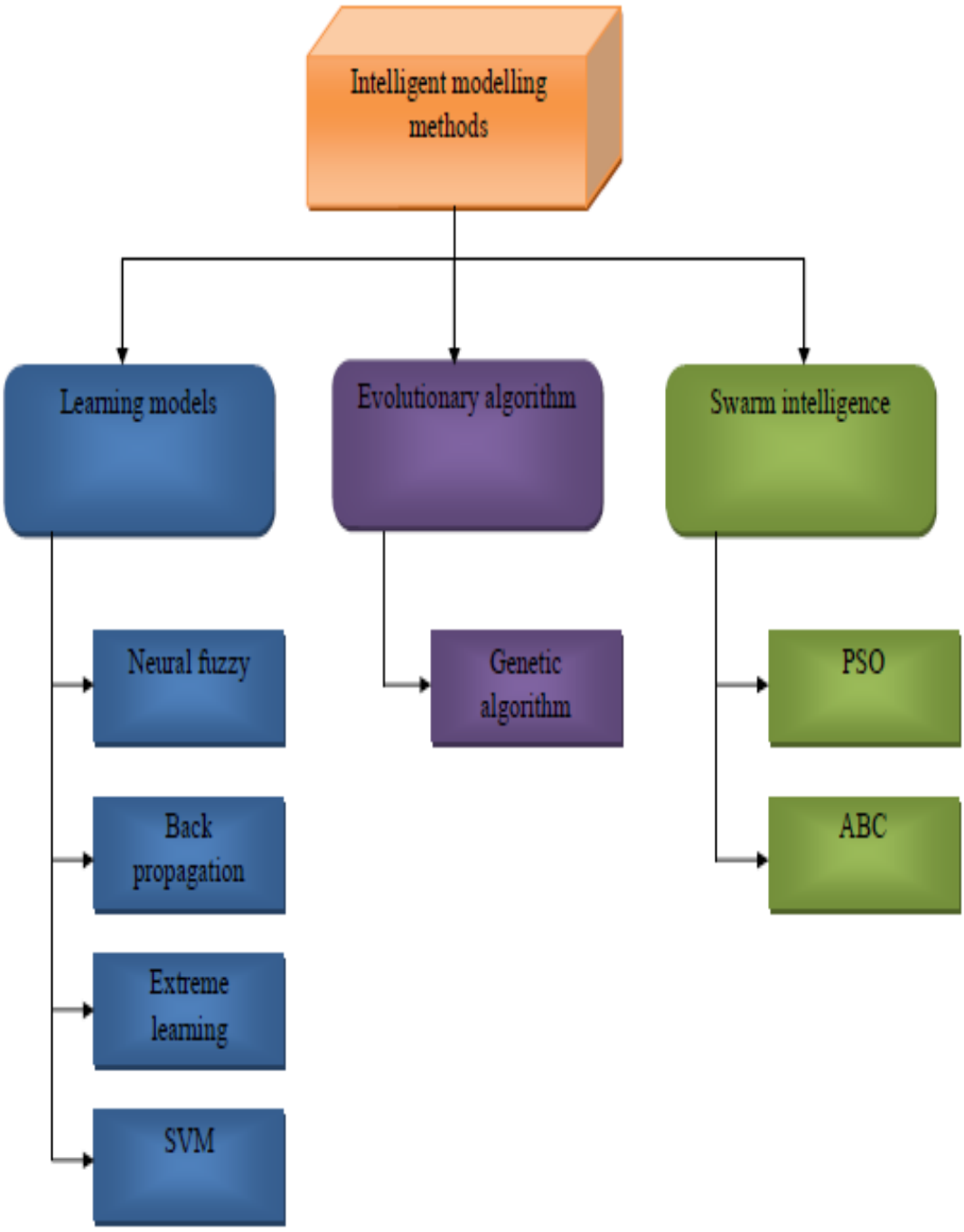

Fig.1. Categorization of the intelligent modelling methods related to the design of boiler

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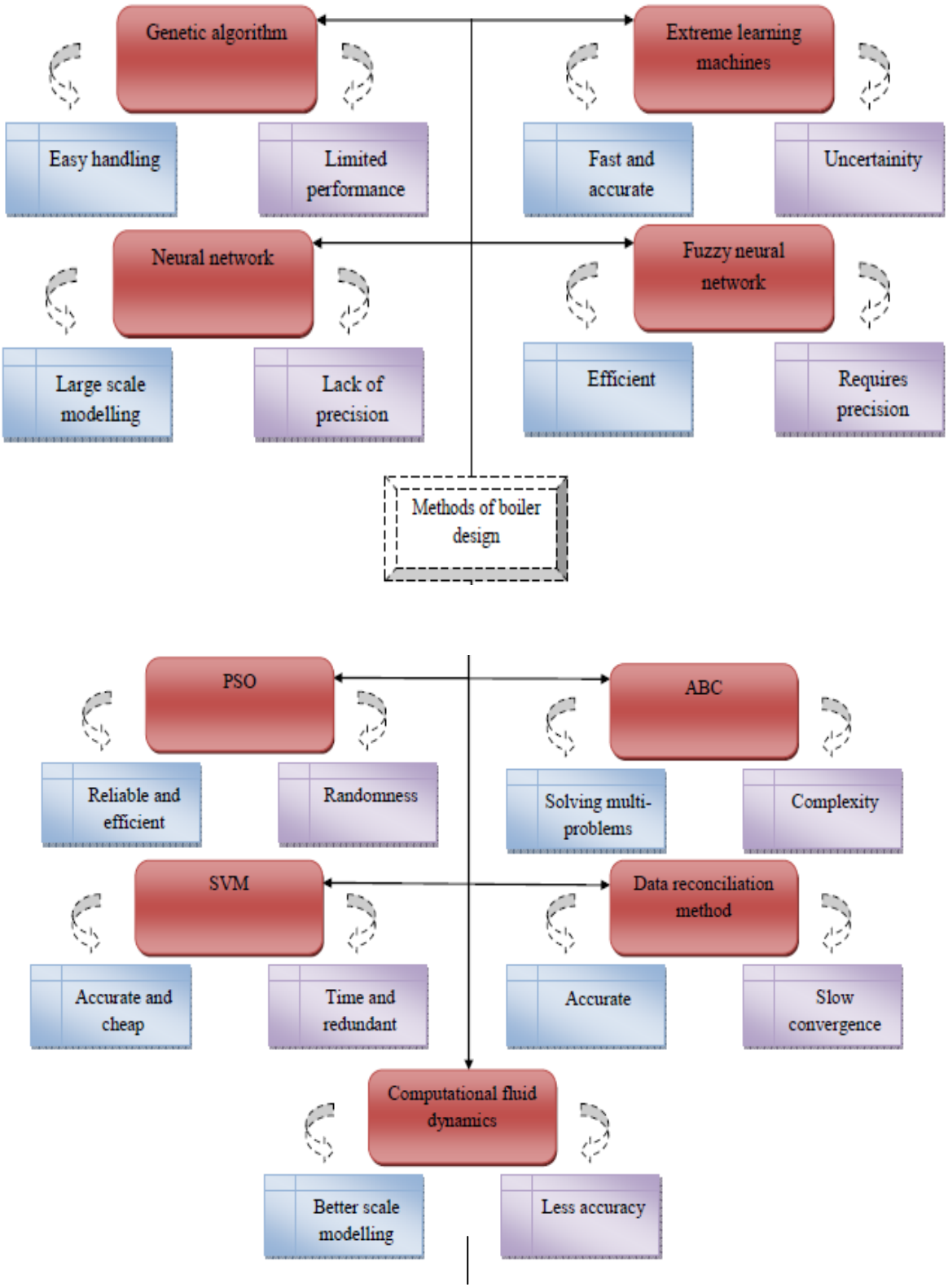

Fig. 2. Taxonomy of different methods concerning the boiler design

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Table I. Review on Staff of the Art Design Methods

Author [Citation]	Adopted Methodology	Features	Disadvantages
Beyhan and Kavaklioglu [1]	Extreme Learning Machines	High degree of modelling, better learning ability and fast learning speed	Uncertainty due to arbitrary initialization
Hengyan et al [2]	Neural Network and Genetic algorithm	Ability to handle nonlinear and large scale modelling	Lack of precision in the objective function often results in poor modelling
Liu et al [3]	Fuzzy-neural network and Gaussian	Efficient modelling and control	Requires precise system knowledge
Kljajic et al [4]	Neural Network	Good prediction reliability and computationally efficiency	Randomness in learning process
Secco et al [5]	Genetic algorithm	Easy handling of unknown characteristic of system	Limited real-time performance
Sayed et al [6]	Particle Swarm Optimization	Good convergence rate	Affects due to premature convergence and curse of dimensionality, High dependency on algorithm parameters and nature of the search space.
Yang et al [22]	Back propagation-least square support vector machine-genetic algorithm-fuzzy association rule mining	Accuracy, low cost	Execution time is high and extraction of large number of redundant rule
Szega and Nowak [23]	Data reconciliation method	Better accuracy, diminished uncertainty	Derivatives calculations, Jacobian actualization, matrix inversion, slow rate convergence, high computational effort
Song et al [24]	Improved artificial bee colony	Solver non-linear and multi-faceted problem	Multisegmented and conditional improvement often leads to complexity
Athanasios et al [25]	Computational fluid dynamics simulation method	Cost reduction, time reduction, handling multiple problems, unlimited level of detail	Less accuracy, simplification is needed
Liu and Bansal [26]	Non-dominated sorting genetic algorithm-Computational fluid dynamics	Better convergence, solve non-linear problems, non-Sensitive towards weights	Requires improvement in terms of precision
Vandani et al [27]	Genetic algorithm, PSO	Easy handling of unknown characteristic of system, good convergence rate	Limited real-time performance, high dependence on algorithm parameters and nature of search space.
Secco et al [28]	Computational fluid dynamics, Genetic algorithm	Ability to handle nonlinear and large scale modelling	Lack of precision in the objective function often results in poor modelling

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III. RESEARCH GAPS AND CHALLENGES

A. Research Gaps

The present study focused on a survey of design of the Small-scale boilers, its operational behavior and the customer satisfaction. The boiler load was identified as the parameter with the highest statistical influence on the annual fuel utilization efficiency. The load of the higher variable is statistically more often together with higher efficiencies based on the investigation on the types of boilers. Subsequently, annual fuel utilization efficiency (AFUE) creates a greater influence from the total number of boilers starts per year and the mean number of full load hours per boiler. However, fewer starts show better efficiencies in correspondence to the load of the boiler and full load operating hours. Further, the thermal performance of the boiler operating under with conditions is generally higher than those boilers installed in conventional buildings. Generally, the thermal performance of the conditional boilers and existing boilers shows higher performance. However, the statistical analysis of the new buildings allows it to operate with higher performance. The predictability of the thermal performance exhibited by the existing buildings have chance to reduce due to the scatter of the results.

In general, the connection of small- scale pellet boilers in existing buildings seems to produce more errors than the connection in new buildings. It is due to the reason of lacking knowledge about the requirements of modern pellet boilers as well as missing information about the real heat energy demand of the existing building which often lead to a wrong sizing of the boiler. In many countries, the detailed study regarding the new building where is to connect the boiler is a compulsory event. However, it is exception in case of replacing the boilers. The insulation of the boiler is increased and the heating load is decreased by accompanying the energetic refurbishments.

In contrast, the design of heating systems is strongly influenced by the legal framework conditions. This has proved by the Germany since their use is mandatory for a public funding through the use of high efficient circulation pumps. The design criteria and the efficiency of the heating system have influence on the development of funding programs. The research regarding the design of the heating system and its requirement against the usage of the funding programs is necessary. The satisfaction of the participating residential customers with their pellet boiler should be very high. Thus it is clear that the design and operation of the boilers is varied according to the full satisfaction of the customers.

B. Challenges

The rapid climatic change along with the rising demand of energy makes to further increase the energy cost over the long term. Although, such rises cannot be avoided, several steps are taken to enhance the efficiency of the energy- intensive plant and processes. Subsequently, in case of boiler, many steps can be taken to improve the performance and energy that should be achieve for both short term and long term savings.

Spotting Areas for improvement: The monitoring and targeting techniques must be used to identify and implementing the energy saving measures of the boilers. Based on the industrial sector where a company operates in, these technique may varies and the cost of the boiler and energy usage may also get varies. Hence, it is an essential part to implement the energy management scheme in an efficient manner.

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Efficiency of combustion: Efforts must start in the boiler itself, where operators need to aim for the best possible combustion efficiency. There is need of perfect mix of fuel and air for generating the maximum amount of the heat to be generated during the combustion. However, the usage of the matching the correct quantity of fuels to the right amount of oxygen also requires remarkable constant monitoring. Hence this constant monitoring technique controls divers factors affects the efficiency of combustion. The optimum combustion process provides just enough excess air to completely burn the fuel, with the exact quantity depending on the fuel being used. The minor adjustment or repair is needed in the boiler if the oxygen level rises over time.

Rapid heat transfer: The efficient conduction of heat is provided to have the perfect heat transfer. However, fouling can also be a problem on the "wet" side of the boil er too. Since any solid contaminants can cause a build-up of scale, the quality of water is one of the major key to consider. As the time extends, this can accumulate, effectively acting as unwanted insulation. Hence, this combustion is controlled using the regular boiler blow down. In addition, the usage of chemicals such as ammonia and hydrazine can also stops such type of contamination. Some of the key parameters including conductivity, pH, dissolved oxygen, sodium, silica, hydrazine, phosphate, ammonia and chloride can also play a vital role in ensuring good long-term boiler chemistry.

Tracking consumption: According to the good energy management of the boilers, Steam metering throughout the entire distribution system is considered as the crucial point. This produce separate billing, or target energy saving measures and thus the efficiency of energy is encouraged. Operators need to know the mass of steam moving around the plant, since this equates to the energy flow. In contrast, swirl meters have lower maintenance requirements and deliver greater accuracy – especially in applications where the steam flow varies over a significant range. The frequency of the secondary rotation is directly proportional to the volumetric flow rate of the fluid, without any need to compensate for changes in pressure, temperature or density. Completely, the meters only need to know the temperature of the steam to calculate the mass flow. Based on aforesaid review, overall summary associated with the design of boiler is illustrated below.

a) The generation of the boiler must be depends on the measurement of the boiler. Thus more steam can be saved. Optimise the combustion process by monitoring the flue gases. The incomplete combustion is also get reduced by careful monitoring process.

b) The efficiency of the boiler should be always maintained at maximum level.

c) Robust and accurate instrumentation should be developed, such that it should be easier to maintain and high resistance to problems such as drift.

d) The mass flow of the boiler is measured often before measuring the volume flow of the boilers.

C. Review Outcome

Based on the description of the works related with modeling and controlling of the boiler design process, it can be asserted that the role of artificial intelligence is more. The primary intelligent methodologies such as ANN and Fuzzy inference system have been adopted in [1] [3] and [4]. The second category of artificial intelligence such as genetic algorithm and particle swarm optimization has been adopted in [5] [6] and [2]. Since the need of exploiting the intelligence concept is essential in accomplishing precise boiler modeling, we have intended to work on it. However, such intelligent methodologies suffer from few renowned issues, as described in Table I.

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IV. CONCLUSION

Boiler is a closed vessel in which water or other fluid is heated. However, the heat efficiency is increased using a large amount of power. Reduction in the amount of energy a boiler uses will increase the overall efficiency and profit of the boiler. Hence, the present study focussed on the literature survey concerning the design of boilers. From the review, diverse intelligent modelling methods have taken into account. The categorization of the intelligent modelling methods and their features and challenges against the boiler design has described. Further, the points about the maintenance of the effective boiler have also described.

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