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Optimization of process parameters through fuzzy logic and genetic algorithm – A case study in a process industry

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ABSTRACT

The simultaneous generation of steam and power, which is commonly referred to as cogeneration, has been adopted by many sugar mills in India to overcome the power shortage. It becomes an increasingly important source of income for sugar factories. The problems faced by the sugar mill industry arise mainly due to failures of either the complete system or some specific components during the cogeneration process. This paper presents the failure analysis of the boiler during the cogeneration process and provides solution to overcome these failures. The failures frequently occur in the screw conveyor and in the drum feeder of fuel feeding system and the grate of the boiler. In this research work, the statistical tools viz., Failure Mode and Effect Analysis (FMEA) and the Taguchi method have been applied to investigate and alleviate these failures. Since conventional FMEA has some limitations and Taguchi method does not give better solution, fuzzy FMEA has been employed to overcome the limitations and genetic algorithm technique has been applied to obtain failure – free system during the cogeneration process.

1. Introduction

The growth of Indian economy is constrained by shortage of power, which is one of the significant constraints. Therefore simultaneous generation of steam and power, commonly referred to as cogeneration, has been adopted in many of the sugar industries [1]. A steam generating boiler is one of the essential prime movers used in cogeneration process and nevertheless boiler failures are one of the major causes for unexpected shutdown of plant, leading to a great loss of production [2]. This research work has been carried out in one of the leading sugar industries located in Tamil Nadu as a case study. The boiler used in the sugar mill is a high pressure and water tube boiler type which is vertical and top supported. The working pressure, generating capacity and steam temperature of this boiler are 66 kg/cm^2, 75 tonnes/hour (T/h), and 485 °C respectively. The main components used in cogeneration boiler are fuel feeding system, furnace (grate), super heater, attemperator, economizer, air pre-heater, Forced Draught (FD) fan, Induced Draught (ID) fan, dust collector, boiler feed water pumps and some auxiliary equipments [3].

The fuel feeding system consists of a storage bunker (silo), drum feeder and a screw conveyor. After extracting sugar, the remaining fibrous residue, which is called bagasse, is used as fuel in the boiler, otherwise, it would be conveyed to the storage facilities. In order to compensate the shortage of bagasse, other fuels such as palm boom, wood chips and cane trash are looked for. This boiler is designed to burn bagasse (B), palm boom (PB), cane trash (C) or a mixture thereof [4,5]. The fuel is fed to the vertical column of the storage bunker (silo) from the belt conveyor. The combination of drum feeder and screw conveyor combination is intended to feed desired quantities of bagasse to the furnace.

The drum feeder extracts bagasse from storage bunker and the quantity extracted is proportional to the speed of rotation of the drum. The extracted bagasse is fed to the screw conveyor which transports the same longitudinally and further into the chute which connects the conveyor and pneumatic distributor. In fact, four such assemblies are available per boiler in the system. Fuel is burnt in suspension as well as during the forward travelling grate surface. Later the ash is continuously discharged over the front end of the grate into the ash handing system. The formed flue gas is passed around the water tubes and further through the economizer, air pre-heater, super heater, dust collector and finally to the air precipitator. Thus the steam generated in the boiler is utilized for power generation. In the above-mentioned boiler, failures are frequently

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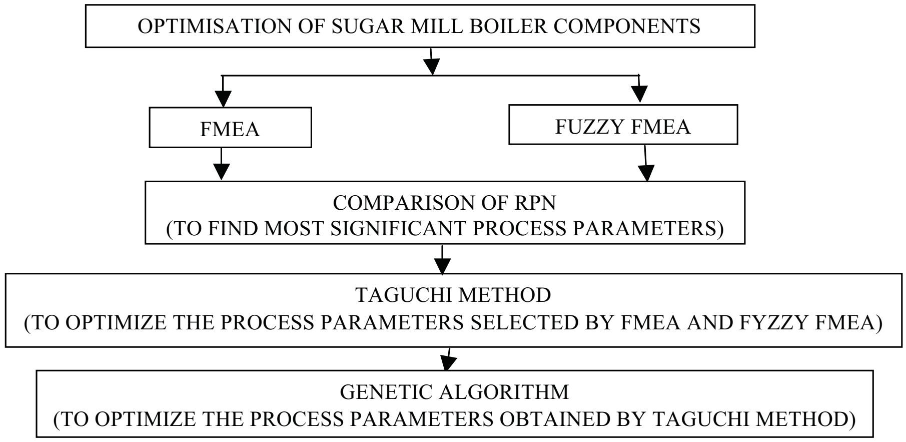

Fig. 1. Methodology of research plan.

Table 1
Traditional FMEA scales for RPN.

Occurrence (*O*) Severity (*S*) Detection (*D*)	Scale	Occurrence rate	Detection probability (%)
Remote	1	<1:20,000	86–100
Low	2/3	1:20,000/1:10,000	76–85/66–75
Moderate	4/5/6	1:2000/1:1000/1:200	56–65/46–55/36–45
High	7/8	1:100/1:20	26–35/13–25
Very high	9/10	1:10/1:2	6–15/0–5

occurring in the screw conveyor, drum feeder and grate. The work plan for this research work is shown in Fig. 1.

In this research work as shown in Fig. 1, a sugar mill boiler has been selected. The problem identified in the above-mentioned industry is minimizing the failures of the system by optimizing the process parameters. The failures have occurred in the drum feeder, screw conveyor and the grate during cogeneration process. In the first stage, RPN values have been ascertained using FMEA and fuzzy FMEA. The most significant parameters that cause the failures are identified from the comparison of conventional RPN and fuzzy RPN values. Further, these significant parameters are optimized by Taguchi method and subsequently by genetic algorithm in order to obtain failure free system.

Failure Mode and Effects Analysis (FMEA) is a very powerful tool for evaluating and enhancing system reliability that is used in a wide variety of industries including aerospace, automotive, medical, mining, offshore and power generation. FMEA is a widely used engineering tool for defining, identifying and eliminating known as well as potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer [6,7]. A system, design, process, or service may usually have multiple failure modes or causes and effects. In this situation, each failure mode or cause needs to be assessed and prioritized in terms of their risks so that highly risky (or most dangerous) failure modes can be corrected with top priority. The traditional FMEA determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the occurrence (*O*), severity (*S*) and detection (*D*) of a failure. That is $RPN = O \times S \times D$, where *S* represents the severity of the failure, *O* represents the probability of the failure occurrence, and *D* represents the probability of the failure being detected [8]. The severity, occurrence and detection factors are individually rated using the 10-point scale described in Table 1. The minimum value ("no risk") is rated with 1. Failure modes with higher RPN values are considered to be more important and are given higher priorities than those with lower RPN values [9]. However, it suffers from several shortcomings. It has been pointed out that the same RPN can be obtained from different combinations of severity, occurrence, and detection. Although the same RPN is obtained, the risk can be different and the relative importance of three risk factors (*O*, *S* and *D*) is not taken into account. In other words, the three risk factors are given of equal importance, but this may not be the case in practice. The three risk factors are difficult to evaluate precisely. Typically, division is made with the usage of linguistic terms such as low, higher very high. In order to overcome the above shortcomings, fuzzy logic is applied into the conventional FMEA in the present work [10,11].

2. Methodology of fuzzy inference system

Fuzzy logic system is one of the various names for the systems which have relationship with fuzzy concepts like fuzzy sets, linguistic variables, etc. The most popular fuzzy logic systems in the literature may be classified into three types: pure fuzzy logic systems, Takagi and Sugeno's fuzzy system, and fuzzy logic systems with fuzzifier and defuzzifier. The three inputs *S*, *O* and *D* are fuzzified and evaluated in a fuzzy inference engine built on a consistent base of IF–THEN rules. The fuzzy output is defuzzified to get the crisp value of the RPN which will be further used for a more accurate ranking of the potential risks [12,13]. Fuzzy inference system (FIS) is based on IF–THEN rules which can connect multiple input variables to output variable. FIS could be utilized as a forecasting model when input/output data have some uncertainties. Detection assessment methodology is based on FIS and therefore it provides a flexible way for recognizing their effective factors and modelling. Input variables are fuzzified by the fuzzy membership functions and they are imported to fuzzy inference engine. In a fuzzy inference engine, experts' knowledge about failure detection is converted into If–Then rules. Fuzzy inputs are assessed by fuzzy inference engine and finally output or detection score is defuzzified [14].

2.1. Application of the proposed approach to process industry

Taguchi–genetic algorithm approach has been applied to optimize the welding process parameters of friction welding of tube-to-tube plate using an external tool (FWTPET) [15]. The practical significance of applying GA to FWTPET process has been validated by means of computing the deviation between predicted and experimentally obtained welding process parameters. This process yields high quality and defect-free weld joints with enhanced mechanical and metallurgical properties with lesser energy consumption [15]. Although the evolutionary algorithms offer significant advantages over the traditional techniques, they may have premature convergence towards a local minimum. In