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DESIGN AND IMPLEMENTATION OF EVOLUTIONARY ALGORITHM BASED CONTROLLER FOR CALCINER PROCESS

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Abstract

In this article nonlinear characteristics of clinker calciner temperature and its control impact on the clinkerization is provided by designing an evolutionary algorithm based controller. Calciner temperature is one of the significant parameter in Cement kiln control, because it affects fuel consumption and quality of cement. In most of the chemical industries, process exhibits nonlinear characteristics but still linear PID control techniques are used to control such systems.To overcome the limitations of PID controller due to higher degree of freedom, this article is an endeavour to intend an optimized control strategy. This paper present a comparative study of controller techniques to tune a PID and FOCPID parameters for the process. Here a scheme of developing pre-dominant PID controller and Fractional order PID controller(FOCPID) is proposed to deal with the non-linear calciner process. The tuning parameters of both the controllers are optimized by minimizing the objective function using evolutionary algorithms such as Genetic Algorithm (GA),Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO). The performance of the above-mentioned algorithms have been evaluated by comparing the ITAE, ISE and IAE values. The simulation results shows PSO produced better performance than the other algorithm in both the controllers.

Keywords: Cement calciner, PID,FOCPID, Genetic Algorithm (GA), Particle Swarm Optimization Algorithm (PSO),ANT colony algorithm

1.INTRODUCTION

In recent world for the construction of home or any infrastructure development the basic requirement element is cement. In both developed and developing countries in the world, production of cement has grown constant manner [1].Cement industry uses large energy consumption ,heavy resources and hence gives severe resource, energy, and environmental problems. Fundamental material needed for producing cement requires limestone and clay. Manufacturing of cement involves three stages of operations like raw meal preparation, Pyro processing in cement kiln and cement grinding. Pre-calciningtechnology is introduced in new dry process cement industry, which reduces heat consumptions and gas pollutants formation in the rotary kiln system. This technology helps in decomposition of raw material out side of the kiln, because of this reason it reduces all environmental problems. The pre-calcining technology has been widely accepted in cement industry because of much stricter environmental standards and continuous increase in requirement of cement. In industry now a days pre-calciner is the important stages of heating, mostly to carry out the tasks of partial fuel combustion, gas-solid heat exchanges and much of the raw material decomposition[2]. Currently in the field of cement control technology the control and optimization of the calciner parameters plays a vital role. In the varying operating conditions in cement plant it is very difficult to maintain the calciner temperature with in an acceptable range[3]. Industries face great challenges in controlling the calciner process parameters due to their nonlinearity and varying operating point, constraints violations on coal, raw feel feeding and interaction effect[4]. In chemical process, plentiful advanced controller techniques are developed but still PID controller is widely used 90 % of industries[5]. Because, the PID controller provides not only the simple structure but also easy to understand the concept. Adequate performance of process is achieved through this algorithm for majority of applications. To get excellent performance of the plant, controller tuning is necessary for the process[6].But wide experimentation is needed for the proper tuning of the controller settings. If the parameters of the controller not properly tuned it gives instability or deterioration of the performance of the closed loop system. Traditional PID controller has limitations on the degrees of freedom variable and optimal tuning strategy, which gives the failure performance in the non linear process. Now a days to improve the performance of the nonlinear process fractional order controllers are developed. Due to the fractional powers of integral and derivative terms it produces more robust performance and it is affected by much lesser variations than the integer order controller. Optimum values of controller parameters are calculated and applied to the calciner process which provides satisfactory response. During the last few decades researchers widely proposed several evolutionary methods for conventional PID and the fractional order controller to tune controller parameter[7-8].

This paper is discussed in the following way. Description of the calciner process is given in section 2. Section 3 presents model identification and controller design. Section 4 discusses various evolutionary methods for controller tuning.Section 5 shows how PSO based PID controller gives better performance. Finally section 6 concludes the paper.

2.PROCESS DESCRIPTION

Cement manufacturing plant include different stages in the production such as pre-treatment of raw material, preprocessing and post-treatment of clinker . The clinker production is one of the key significance as the quality of the cement depends on the quality of the clinker greatly. Kiln is the heart of the pyro processing unit where the raw meal is heated to approximately 1,500°C temperature. Chemical reactions take place at this temperature and clinker is produced. Higher temperature is required to convert the chemical reactions of materials into cement clinker. In modern cement plant calciner plays an important role in clinkerization process in pyroprocessing units. A strong endothermic reaction occurs inside of the calciner is known as the calcination process(*decarbonizing of the raw meal*).In general the calcination process can be presented by the following equation 1.

$$CaCO_3(s) \xrightarrow{+178KJ/mol} CaO(s) + CO_2(g)----(1)$$

The clickerization process diagram is shown in figure 1.At the preheater zone the heat transfer will takes place. Combinations of preheater and precalciner increase in production, because major decomposition raw material will takes place at the precalciner stage itself ratherthan cement kiln.

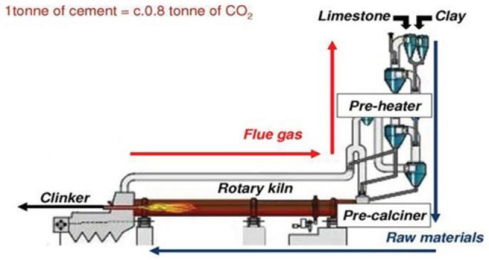

Figure-1 Cement calciner

Because of this reason raw materials spend less time with in the kiln helping to have lesser load ,so it rotate faster resulting in more output. With the help of a tertiary air ,duct the pre-calciner is assisted with hot air from the cooler , so the pre-calciner temperature can be achieved with lesser fuel consumption. Controlling calciner temperature is necessary in cement plant ,because it affects fuel consumption, pollutant emission and the final cement quality[9] .Recent years cement production and environmental awareness are increased as the cement manufacturers are trying to lower their pollutant emissions. The advanced control technologies are important to obtain an efficient, cost saving and increased profit of production which is a complex work for a long term.

3.MODEL AND CONTROLLER DESIGN

(A)MODEL DEVELOPMENT

A mathematical model is developed by using the system identification tool box in MATLAB. Transfer function model and process model are developed for the imported calciner data. Best model has been chosen based on the fit percentage and error values.Figure 2 shows the model output for calciner.

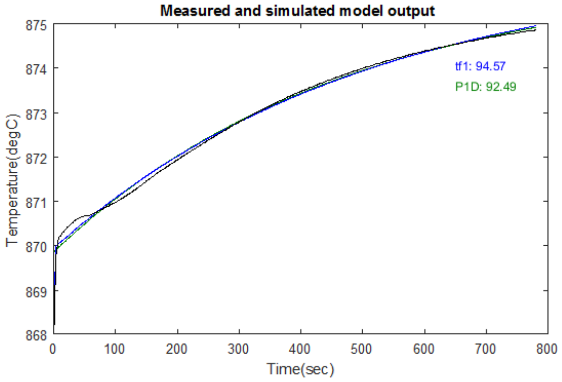

Figure-2 Model output for calciner temperature

Table 1 gives the error values for both models and their fit percentage. From the table 1 we can infer that the transfer function model has low mean square error(MSE) and final prediction error(FPE) and more fit percentage than the process model. Further for the controller design transfer function model has been chosen for best performance.

Table-1:Comparison table for model

Model	Fit percent(%)	MSE	FPE
PID	92.49	.01151	.01163
Transfer function	94.57	.006021	.006145

(B)PID CONTROLLER

Most of the industry having controller (almost 90%) is PID type. The main reason being controller parameters can be easily tuned and it is simple and easy to understanding. But it has limitation, the set of parameters of the controller at one operating point does not provide satisfactory response for wide range of operating conditions. So soft computing based methodology has to be implemented for tuning of the PID controller parameter. The controller representation is given in the following equation

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad \text{---------(2)}$$

K_p-Proportional gain,K_i-Integral gain and K_d-Derivative gain

K_i and K_d are calculated by K_p /T_i and K_dT_d,where T_i and T_d are integral and derivative time constants. [11]Laplace transformation of PID controller is given equation 3.

$$G(s) = K_p(1+\frac{1}{T_i s}+T_d s)$$

--------(3)

(C)FRACTIONAL ORDER CONTROLLER

In recent years fractional order controller is used as one of the control technologies to improve the operating performance of any process industry. A special kind of PID is FOPID controller, where order of the integral and derivatives are fractional rather than integer. Design of such controller has more flexibility because of the expansion of derivative and integral order from integer to fractional order. This helps in controlling a wide range of dynamics system and it is less sensitive for variations in the parameters of the process. It also provides robustness to the plant model against gain variation, noise and disturbance[9].Conventional tuning method is very difficult to determine controller parameter. To get optimum values of the parameters soft computing based tuning methods are implemented to achieve improved results. The two significant parameters λ (integrator order) and μ (derivative order) are determined in FOCPID design .In time domain analysis control signal is represented in the following equation

$$u(t) = k_p e(t) + k_I D^{-\lambda} e(t) + k_D D^{\mu} e(t)$$

---(4)

Representation of controller in Laplace domain as given in equation 5

$$G_C(s) = \frac{U(S)}{E(S)} = k_p + k_I \frac{1}{S^{\lambda}} + k_D S^{\mu}, (\lambda, \mu > 0)$$

------(5)

PID controller select $\lambda = 1$ and $\mu = 1$.PI and PD controllers values are chosen in the following way $\lambda = 1$, $\mu = 0$, and$\lambda = 0$, $\mu = 1$. [12-14]

4.CONTROLLER TUNING

(A) GENETIC ALGORITHM

In 1975 Holland introduced genetic algorithm to analyze the trend and it is familiarized by Goldberg. This algorithm was developed from the theory of evolution to natural biology created by the Charles Darwinian. Stochastic optimization techniques are called evolutionary algorithms simulated by biological evolution.GA technique is derivative free stochastic optimization algorithm based on the mechanism of natural selection and natural genetics .GA population, starts with an initial set of random solutions. Every individual in it population named as chromosomes(binary) provides a solution. The chromosomes developed through successive iterations are called generation. Fitness calculation evaluate the chromosomes in all generation. Next generation is created by crossover operator by merging two chromosome from present generation. Otherwise it uses mutation operator and modify the chromosome. To provide optimum solution higher probability chromosomes are selected for many generations until the algorithm converges to the best. Optimum solution is obtained by after several generations, once the algorithms converge to the best chromosomes. Necessary operators of GA are reproduction, crossover and Mutation are discussed in [15].

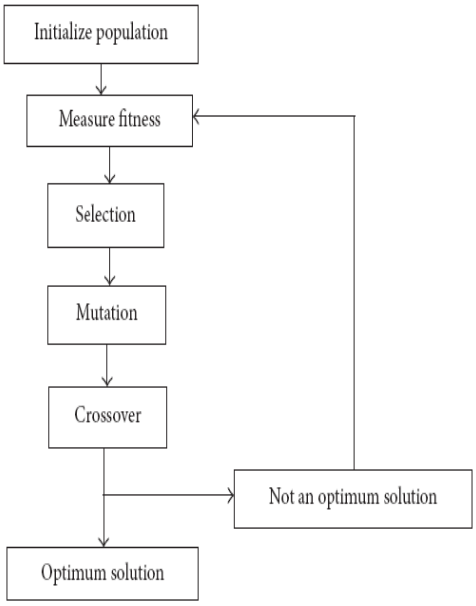

Figure-3 Operational flowchart for GA

Genetic Algorithm Procedure:

Step 1: Encoding of the problem in a binary string

Step 2: Population is generated by randomly

Step 3: Determine fitness of each solution

Step 4: Select pairs of parent strings based on fitness

Step 5: Generate new string with crossover and mutation until a new population has been produced

Repeat step 2 to 5 until satisfactory solution is obtained [3].

GA is easy to understand, do not have much mathematical requirements, flexible, supports multi-objective optimization and easy to exploit previous or alternate solutions. But it requires more computational time and it is slower than some other methods.

(B) PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) technique is proposed by Dr. Eberhart and Dr. Kennedyin 1995,inspired by social behavior of bird flocking or fish schooling [16].Each generation is updated, the PSO is initialized by the population of random solution. Crossover and mutation types of evolution operators are not available in this method. Particle is nothing but potential solution, it flies through the problem space and tracks the present best possible particle in the problem space. Only few parameters are needed for adjustment, the PSO is easy implemented than GA. Updation of each particle is required for every iteration by two best values . One is *P best* ,in iteration the best solution is achieved and the fitness values are stored. Next one is *G best* in the whole population any particle gives the best values that are traced by the optimizer. Every time velocity is changed the particle move towards to its *G best* and *P best* .

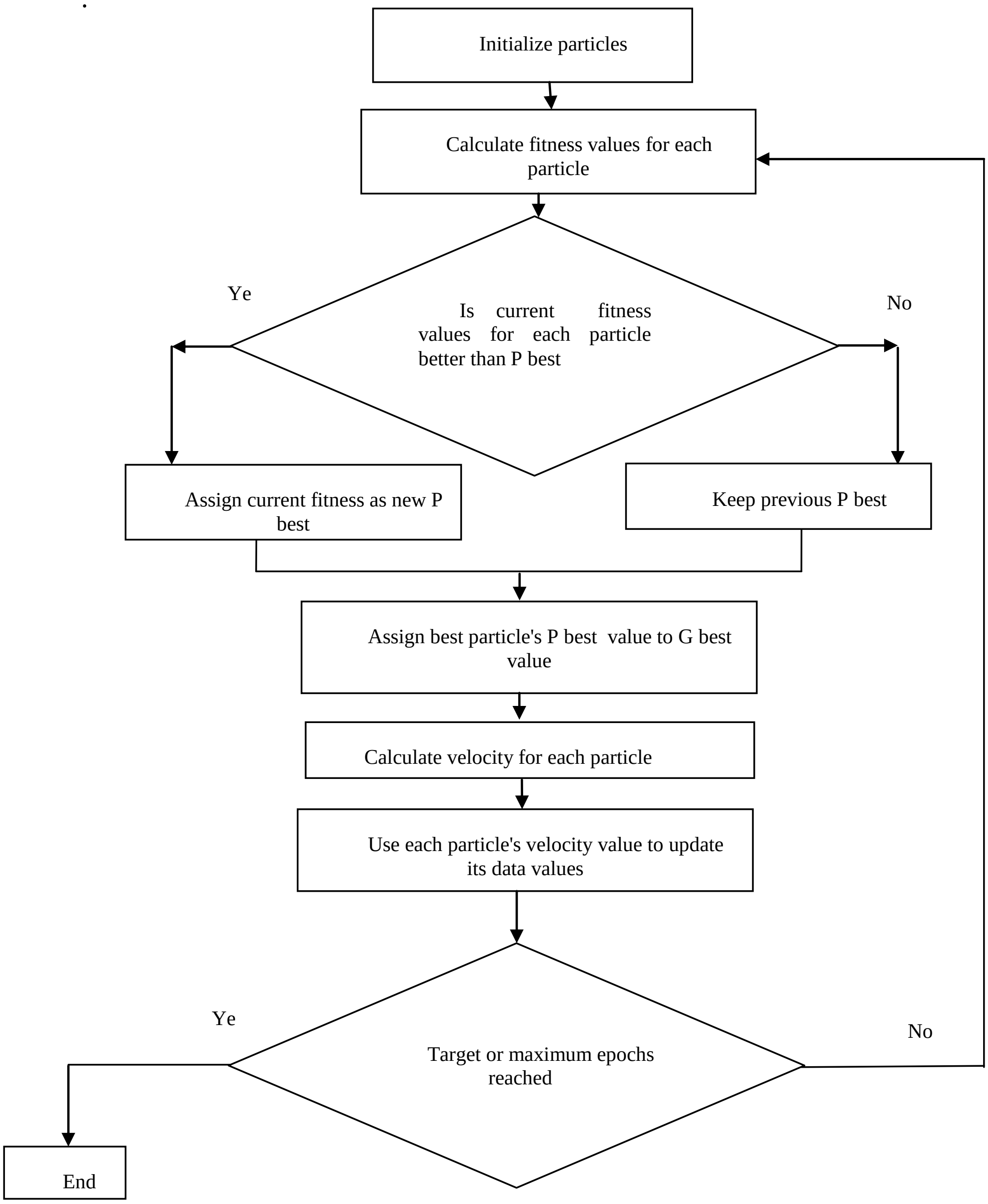

Figure-4 Operational flowchart for PSO

Particle Swarm Optimization Algorithm procedure:

- Initialize all the particles.
- For all particle fitness value is determined. The calculated fitness value is better than the best fitness value(*P best*) in record, set present value as the new *P best*.
- From the overall particle the *G best* value is obtained by which particle having best fitness value.

  Determine particle velocity for individual particle according to equation (6) .

  *v[] = v[] + c1 * rand() * (Pbest[] - present[]) + c2 * rand() * (Gbest[] – present[])* --------(6)

and estimate particle position according to equation (7).

present[] = present[] + v[]-----------------(7)

Where *v[]* is the particle velocity, *present[]* is the current particle (solution). *P best[]* and *G best[]* are defined as stated before. rand () is a random number between (0,1). c1, c2 are learning factors. Usually c1 = c2 = 2

(C)ANT COLONY ALGORITHM

In 1990's ACO concept is introduced by Marco Dorigo. The behavior of ant colonies gives the inspiration for ACO algorithm. Ant Colony [18] Optimization is a metaheuristic, probabilistic technique that searches for an optimal path in the graph based on behavior of ants seeking a path between their colony and source of food.Ants navigate from the source to the food and the shortest path is discovered by the pheromone trails.

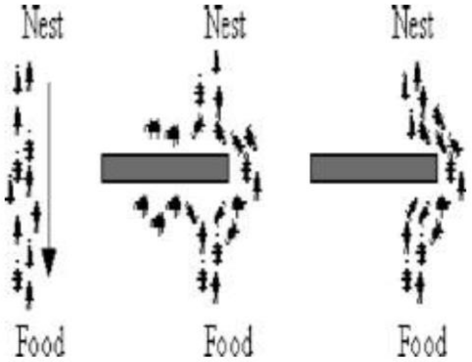

Figure-5 Diagram for ANT colony behavior

Pheromone is a chemical substance that is deposited by the ants to indicate the path travelled by them to the other ants. This substance can evaporate with time. So, the shortest path is identified by the concentration of the pheromone on the trails of the ants.Thus, more pheromone on the path increases the probability of the path being followed. This behavior of the ants in the environment is inspired and is being used to computationally find an optimal path for various optimization problem.Figure 5 illustrates basic behavior of real ant system. Left picture denotes the ants movement in a straight line to the food .An obstacle is introduced in between food and nest, ants chooses random path either right or left illustrated in middle figure. Assume pheromone deposited in the trail uniformly that ants move at the constant speed. Ant will reach the food sooner by choosing left side, when it goes right side it will take long time and having longer path. Finally around the obstacle pheromone accumulates faster in the shorter path.Based on the pheromone deposition ant prefer the shorter path and reach the food explained in right picture. [16]

5.RESULT AND DISCUSSION

Here we discuss the performance of the proposed FOCPID and PID for the cement calciner process in the presence of fuel variations in the output [17]. PID and FOCPID controller parameters are estimated by evolutionary algorithm like GA,PSO,ANT colony.

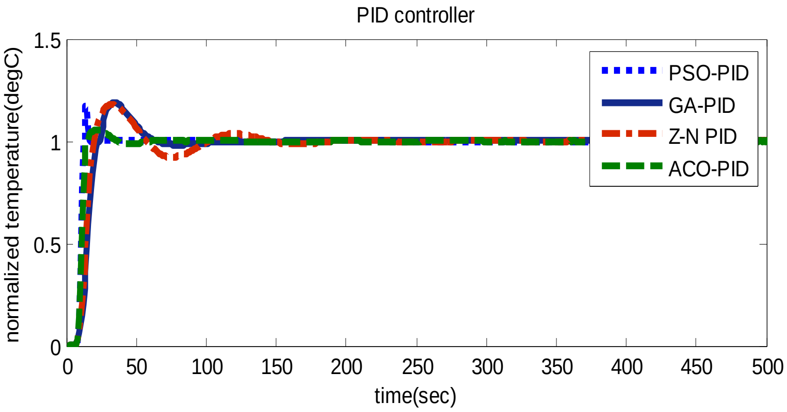

Figure-6 Response graph for PID controller

Figure 6 shows the PID controller response for different evolutionary algorithms. In that PSO based PID controller quickly settled. From figure 7 the simulation results show the PSO based FOCPID controller gives less settling time when compared with the other controller. In all the cases PSO method produces better results than other methods.The FOCPID and conventional PID performance are evaluated by performance metrics such as ITAE,IAE and ISE values shown in Table 2 and Table 3.

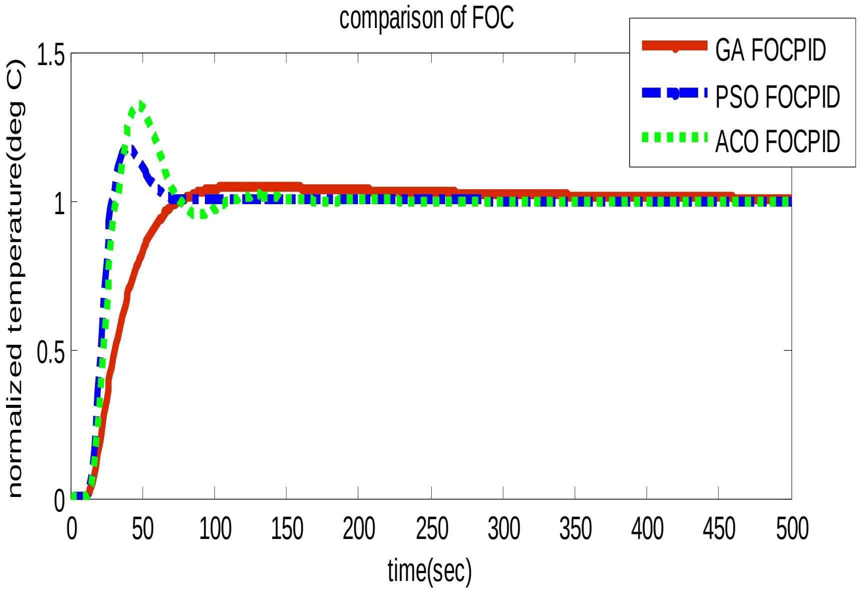

Figure-7 Response graph for FOCPID controller

Table-2 Comparison table for PID controller

Controller	ITAE	IAE	ISE
GA-PID	0.418	0.489	0.194
PSO-PID	0.047	0.038	0.013
ACO-PID	0.82	0.34	0.11

Table-3 Comparison table for FOCPID controller

Controller	ITAE	IAE	ISE
GA-FOCPID	0.111	0.077	0.025
PSO-FOCPID	0.050	0.046	0.016
ACO-FOCPID	0.59	0.11	0.02

6.CONCLUSION

Initially a model that maps the calcinerfuel(input) and calciner temperature(output) has been designed. To improve the controller performance traditional PID controller is replaced with FOCPID controller. Successful endeavor is made by tuning the controller gain parameters using different algorithms by minimizing the cost function like Genetic algorithm and Particle Swarm optimization and Ant Colony Optimization. Perceptive MATLAB simulations are done for the calciner temperature control using these tuning algorithms. After complete implementation, the comparison results show that FOCPID controller performs better than traditional PID. Further, with respect to optimized tuning parameters, it is found that PSO-FOCPID has minimum integral error criteria than GA-FOCPID and ACO-FOCPID.

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