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Intelligent PID Controller for Real Time Automation of Microwave Biodiesel Reactor

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Abstract—**Chemical reactors and PID controllers are two of the most important elements in chemical industry. PID controller has remained, by far, as the most commonly used controller in practically industrial control applications. But most of the chemical reactors operations were unsuccessful due to unlimited certainties of various system parameters. This is due to the fact that the conventional PID controller might degrade or even become unstable for nonlinear process. The paper present the intelligent tuning technique for PID parameters by using Genetic Algorithm (GA) and Inverse Adaptive Neuro-Fuzzy Inference System (ANFIS) model to control in real time microwave biodiesel reactor. This reactor has been designed and tested to produce biodiesel for used cooking oil or animal fat with high efficiency in comparison with conventional biodiesel reactors. LabVIEW based software is used for interface, measurement and control of the full system.**

Keywords-biodiesel; microwave reactor; PID controller; gnetic algorithm; ANFIS, LabVIEW

I. INTRODUCTION

Used cooking oil from restaurants and food outlets are a source of biofuels [1, 2]. Biofuel is not new, but using microwave technology as a way for esterification or transesterification is new, it brings all the benefits of sustainable fuel but without the negatives [3, 4]. The biodiesel derived from waste cooking oil, is one of the options to replace diesel [5]. It is obtained by transesterifcation that compromise triglycerides with methanol in presence of catalyst [5] and it is affected by different parameters: reactor, molar ratio between alcohol and triglycerides, reaction time, catalyst, reaction temperature, free fatty acid, and water contents of the oils or fats [6].

The microwaves operating at power<100W with a frequency of 2.4GHz, are able to drastically reduce chemical reactions from hours under conventional heating to just minutes and can be used in multiple applications. Development of a multipurpose prototype chemical reactor using microwave assisted chemistry, for the continuous production of bulk chemicals at commercial production rates(kg/hr), was achieved by combining, for the first time, microwave continuous flow reactor technology and microwave sources having both tunable frequencies and power in order to optimize the reaction temperature. One of the main achievements for this development is use of the microwave flow reactor in speeding up the transesterification reaction in the production of biodiesel from waste oil. The use of this system has lead the reaction of oil and solvent to be completed in minutes rather than in hours if compared like for like with the conventional thermal transesterification reaction. Also the ratio of solvent to oil and percentage of catalyst were reduced drastically using the microwave flow reactor. This developed technology can utilize any waste cooking or acidic seed oil as biofuel for combined heat and power generation or to convert them to biodiesel. Fig.1 shows the advanced microwave biodiesel system.

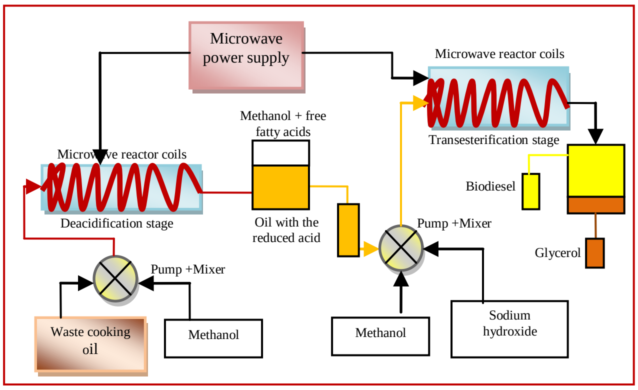

Figure 1. Biodiesel system

Automatic real time monitoring and process control of the microwave biodiesel reactor is required due to the changes of the dielectric properties of the chemical samples during the heating process. In order to sustain the optimum conditions for the chemical reaction, keeping a constant cavity temperature is essential; this is defined by the user in the control software. Fig.2 shows the variability in temperature for a fixed power (nominally set to give around 40°C) in the microwave biodiesel reactor system.

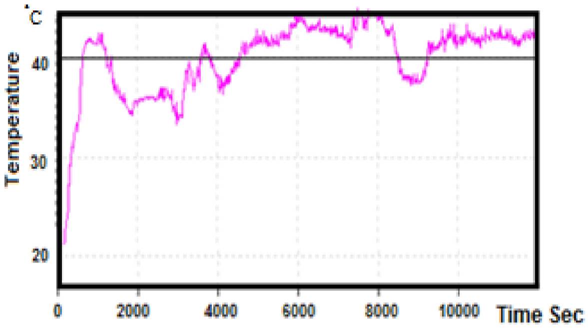

Figure 2. Variability in microwave biodiesel reactor

From Fig.2, we can see the instability in temperature control due to the sample variability. The control system should be able to maintain stability and performance level in spite of uncertainties in the system [7]. An unsuccessful reaction step due to any changes in the reaction conditions can lead to incomplete conversion or damage to reactor and could lead to a significant risk. Fig.3 shows the block diagram of biodiesel production from waste cooking oil with real time monitoring and process control.

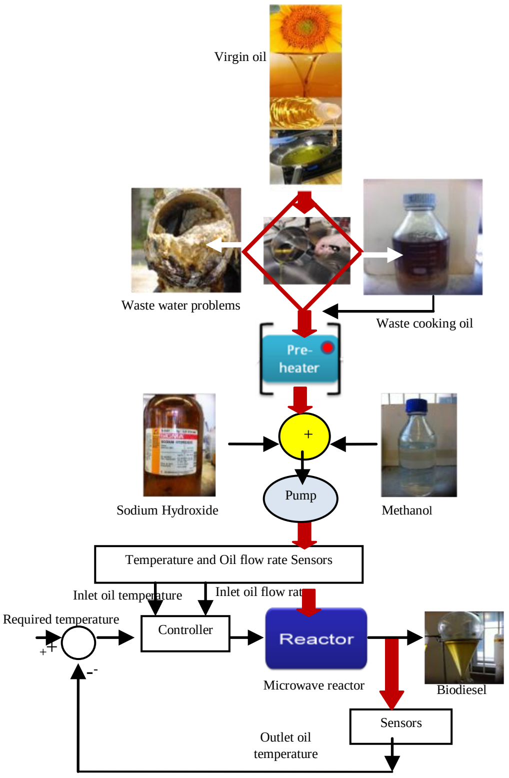

Figure 3. Block diagram for biodiesel production and control

Proportional-integral-derivative (PID) controllers are the most widely used controller in practically industrial control applications [8- 10] because of their simplicity, robustness in a wide range of operating conditions. To yield satisfactory results, the values of PID parameters must be tuned according to the characteristics of the process. However, PID control performs well only at a particular operating range and it is necessary to retune the PID controller if the operating range is changed. This limitation of PID control rapidly become evident when applied to more complicated system such as those with a time-delay, poorly damped, nonlinear and time-varying dynamics. Therefore, it might degrade or even become unstable for nonlinear processes with a range of operating conditions [11]. Fig.4 shows unsuccessful experimentations for the conventional tuning methods to tune the PID parameters on the real time microwave biodiesel reactor at 30°C required temperature and 300ml/min oil flow rate. Fig.5 show the controller cannot reject the disturbance as -20% changes in oil flow rate.

Fig.6 shows comparison between fuzzy controller for the microwave biodiesel reactor [12] and the conventional PID controller at multi set point tracking (required temperature beginning from the nominal temperature value of 30°C and changing rise to35°C then down to 30°C).

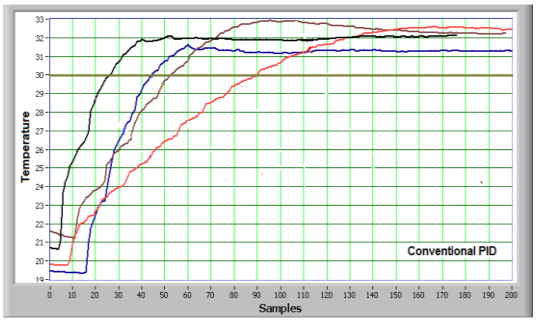

Figure 4. Unsuccessful tuning for PID parameters on real time microwave biodiesel reactor (at 30°C required temperature)

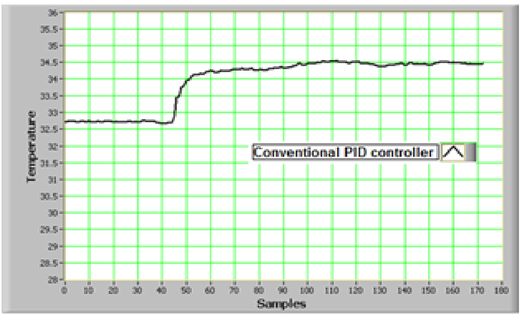

Figure 5. Conventional PID controller cannot reject the disturbance

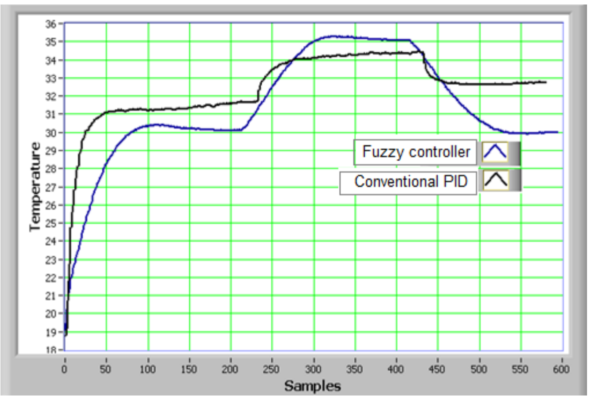

Figure 6. Comparison between fuzzy controller with conventional PID controller for microwave biodiesel reactor

II. CONTROL SYSTEM

The biodiesel transesterification reaction is one of the complex and high nonlinear processes. It involves a wide range of operating conditions, as several signal and stages interact with each other. So, the first problem in controller design is the system model [13], when controller is to be built without having an accurate mathematical model of the system or the mathematical model cannot deal with ill-defined and uncertain systems, then the presence of uncertainties can make mismatch between the formulated mathematical model and true process, which may degrade the control performance and would lead to serious stability problems. To solve these problems, the intelligent technique which describes the dynamic behavior operation by nonlinear structures such as fuzzy systems and neural networks, been adapted [14]. Genetic algorithm is used to tune the PID parameters to be working well at set point tracking and at disturbance rejection, based on the adaptive neuro fuzzy inference system (ANFIS) model for advance microwave biodiesel reactor.

A. Adaptive Neuro-Fuzzy Inference System(ANFIS) model for microwave biodiesel system

A fuzzy inference system employing fuzzy if-then rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analysis [15]. The advanced microwave biodiesel reactor is modeled by using an ANFIS model [16]. ANFIS is widely used in complex system studies for modeling control or parameter estimating [17-19]. The objective of ANFIS is to optimize the parameters of given fuzzy inference system by applying a learning procedure using a set of input-output training data.

B. Genetic Algorithm(GA)

Genetic algorithm is guided by the mechanisms of three operators: reproduction, crossover and mutation. GA initializes by population of n randomly encoded chromosomes. The objective function of generated population is then evaluated. The selection algorithm chooses individuals for reproduction on the basis of their relative fitness. To form new offspring the chromosomes are crossed over with crossover probability Mutation is then applied with determinate probability.

The PID parameter tuning procedure is described in Fig.7. ANFIS model for the system gives all possible information about the plant which is required to tune the PID controller genetically. The online genetic algorithm proved difficult to test due to fact that the simulations cannot be run in real time [20]. GA then is used as offline stage for tuning the PID parameters based on the ANFIS model which it is has online updating for any changes as shown respectively in Fig.8 and Fig.9.

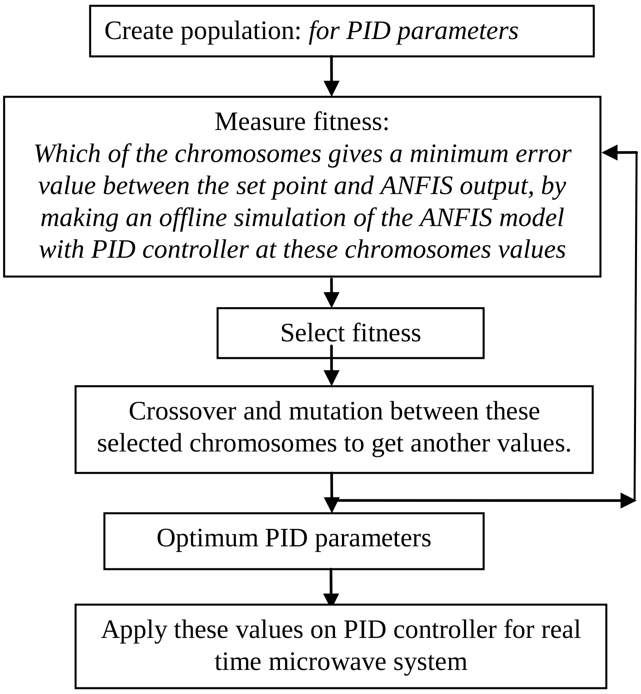

Figure 7. GA process in microwave biodiesel reactor

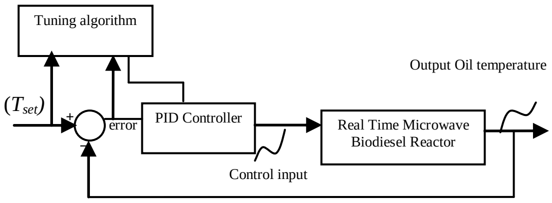

Figure 8. PID Controller procedures

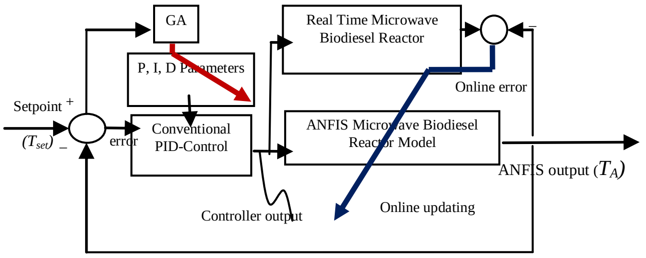

Figure 9. Genetic tuning algorithm for PID parameters based on ANFIS model

III. CONTROLLER DESING

The objective function used in this work is given in (1), (T_{set}) is the desired reactor temperature (set point), T_A is the ANFIS output temperature, and T_{Max}, maximum ANFIS output. The GA routine is to minimize this fitness value of absolute error (E) as in Fig.10.

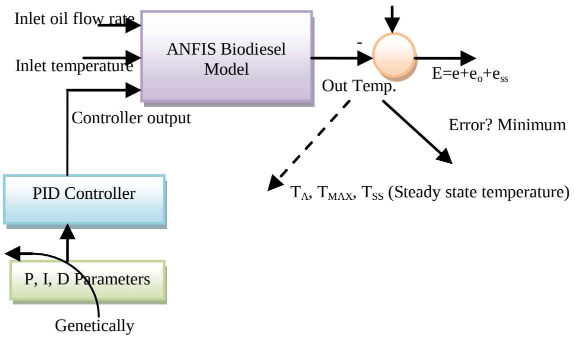

Figure 10. Fitness function block diagram

$$E=e+e_{ss}+e_o \qquad (1)$$

Where

e: error between the setpoint and ANFIS output.

$$e=|T_{set}-TA| \qquad (2)$$

e_{ss}: steady state error

$$e_{ss}=\lim_{t\to\infty}e(t) \qquad (3)$$

eo: overshoot error

$$e_o=|T_{set}-T_{Max}| \qquad (4)$$

T_{Max}: Maximum ANFIS output temperature

The GA starts with a random population being initialized. This can be easily achieved in LabVIEW using the random number generator as shown in Fig.11. Three random populations each of the required size were initialized to represent the proportional gain, derivative gain and the integral gain.

The objective function is used to provide a measure of how individuals have performed in the problem domain. In the case of a minimization problem, the fit individuals will have the lowest numerical value of (E) which is given by (1). The ANFIS model is used to select the fittest individuals corresponding to the lowest values.

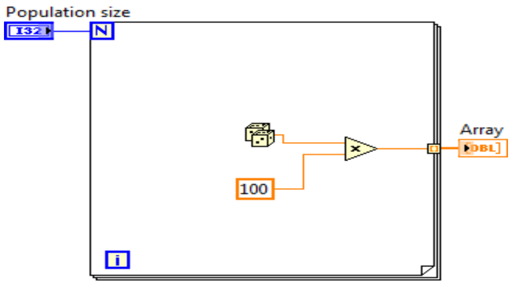

Figure 11. VI for initial random population

The crossover operator is mainly responsible for the global search property of the GA. The basic idea of the step is to produce a new member in the population whose value is determined by two parents existing in the population. Crossover was implemented by randomly selecting two entries and replacing the least fit of them by the weighted average of the two as shown in Fig.12.

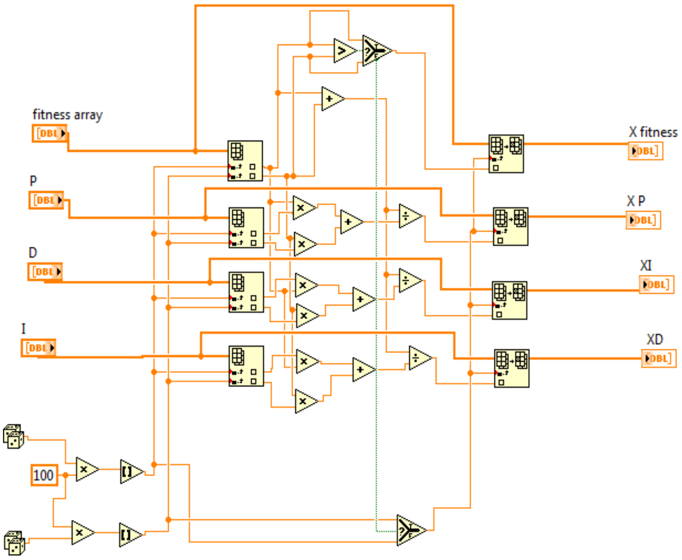

Figure 12. VI for crossover

After crossover is performed, mutation takes place. The mutation operator is used to inject new genetic material into the population. Mutation randomly alters a variable with a small probability. The random number generator was used for both random selection of a member from the current population and to replace it with a new random value as shown in Fig.13.

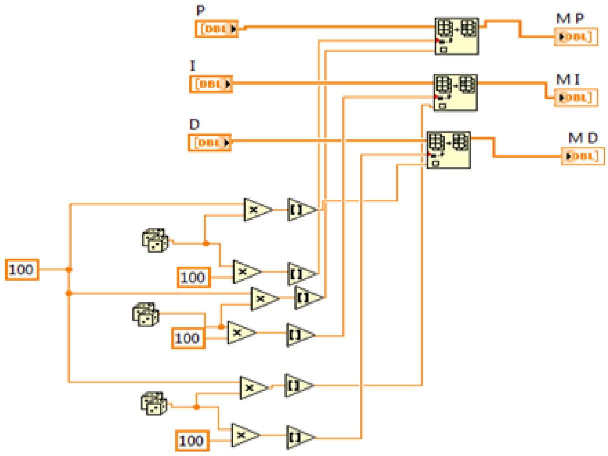

Figure 13. VI for mutation

VI. EXPERIMENTAL RESULT

The PID controller is designed using LabVIEW. The input of the controller represents the error between measured temperature and set point (required temperature). The output of PID is the control signal applied to the biodiesel plant. The controller working at (5s control sample interval) and (300ml/min flow rate). Fig.14 shows the controller implementation as follows:

1- PID controller was tested to track the set point beginning from inlet oil temperature to required temperature equal to 30°C.

2- The controller was then subjected to a multiple set point tracking beginning from the nominal temperature value of 30°C and changing up to 35°C then down to 30°C.

Fig.15 shows the controller comparison between the genetically tuning PID controller and conventional PID controller at set point tracking (required temperature equal to 30°C). The disturbance was then introduced. The nominal feed in oil flow rate was reduced by 20% and 10% then rising by 30% as shown in Fig.16.

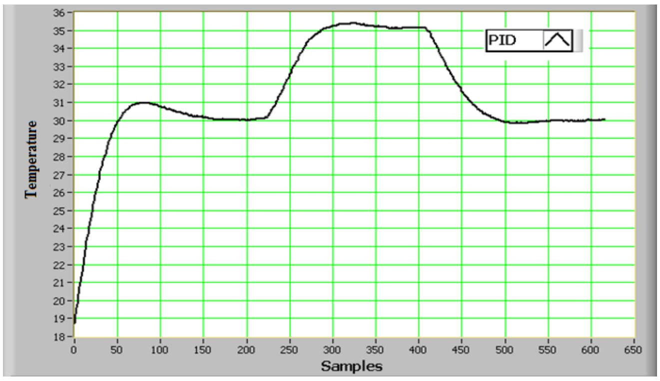

Figure 14. Intelligent PID controller at multiple setpoint tracking

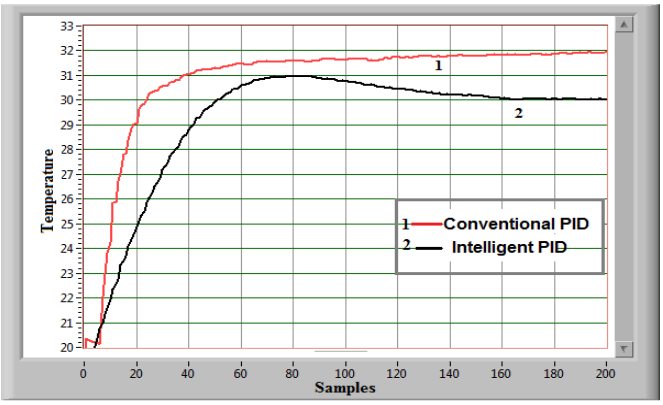

Figure 15. Comparison between intelligent PID controller and conventional PID controller (setpoint equal to 30°C)

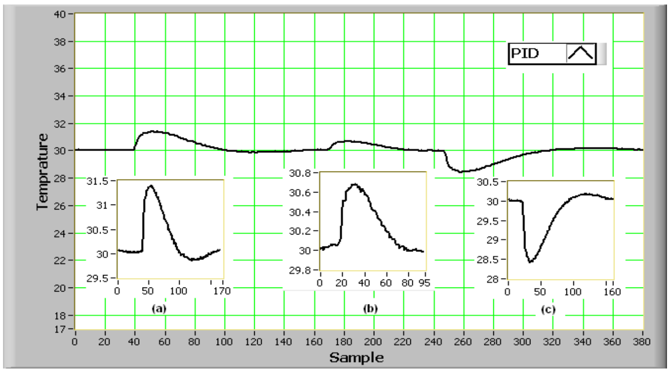

Figure 16. Disturbance rejections (change the oil flow rate -20%, -10%, +30%) for the Intelligent PID controller

IV. CONCLUSION

The Intelligent PID controller has been developed for real time nonlinear process control (Microwave biodiesel reactor). The design method used ANFIS model and GA to realize PID tuning parameters. The experimental results illustrate that the proposed controller design gives good control performance in set point tracking and in disturbance rejection. LabVIEW based software is presented and used for tuning and implemented the PID control with real time monitoring.

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