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A Hybrid Intelligent Control Model for Regulating pH In Industrial Chemical Process

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Abstract **– This paper present a hybrid intelligent control model for pH regulation in industrial chemical process. The dynamic model of pH system was developed as first order plus delay time (FOPDT) process in the form of a transfer function. A proportional integral and derivative (PID) compensator model was initially designed using PID Tuner in MATLAB. Thereafter, a Fuzzy Logic system employing linguistic variables was designed using Fuzzy Inference System (FIS) in the MATLAB software tool. The gains of the PID algorithm were combined with the Fuzzy Logic system to produce the proposed hybrid intelligent Model called Fuzzy-PID. The Model was incorporated into the loop of pH regulating process whose values range from 0-14 in the pH scale. The process analysis was modelled in MATLAB/Simulink environment to examine the effectiveness of the hybrid system. Simulation was initially conducted considering loop response of pH system in terms of step input without the addition of the proposed intelligent hybrid model and the step response shows that the system was not able to reach desired pH set value. A PID controller was simulated in a closed control loop of the pH neutralization process and the step response indicated that the desired pH value was achieved. But the PID control system showed some degree of instability. The fuzzy-PID was implemented as part of the component of the closed loop pH control system and the step response obtained revealed that an improved performance was obtained and the system attained the desired pH value with no instability. In order to validate the effectiveness of the proposed system, simulations were conducted in acid, neutral and base media with pH setpoint target of 5, 7 and 9 respectively on settling time, rising and overshoot as well the error performance analysis with Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral Time Absolute Error (ITAE). It was observed less error performance indices were offered by the hybrid model (FPID) control pH neutralization process compared to PID controller in various media – acid, neutral and base. Generally, the results obtained showed that the proposed hybrid system was able to maintain the setpoint pH values in the various media than individual model.**

Keywords-Compensator, CSTR, Fuzzy-PID, Intelligent, Hybrid, PID Neutralization

I. INTRODUCTION

The conventional control models are increasingly being replaced by more sophisticated control strategies. When the process can be reasonable described or represented accurately in advance, the application conventional control like the proportional integral and derivative (PID) controller become suitable. Nevertheless, in a situation that the process (or plant) dynamics are difficult to model precisely probably due to environmental uncertainties, it may be difficult to use the conventional controller design techniques [1], for this reason, the control of systems with complexities, uncertainties and nonlinearities has become an issue of considerable importance to researchers and different advanced techniques have been proposed in literature [2], [3], [4], [1].

A big drive has been seen in the academic community to design new control systems, either by traditional or contemporary methods. Introducing an ingenious control system can be the key factor in improving performance as well as for dealing better with the challenging features of nonlinear and complex processes. In general, when implementing conventional control systems, a reasonable performance is attained over a narrow operating range. However, when a wide range of process tasks is a prerequisite, nonlinearity become more evident and hence, the control performance may be sacrificed [5]

Application of intelligent techniques in process control systems with reasonable level of autonomy should enhance performance even in the presence of significant uncertainties and nonlinearities in the systems and environment. This should be able to compensate for certain failures without human intervention, these systems have evolved one time from conventional control systems combining intelligent methods to more advance techniques involving hybridized intelligent systems. There has been excitement in the field of intelligent process control which has attracted more attention with appreciable progress in the area of Fuzzy control, neural network, Genetics algorithms and Expert systems etc [1]. It is possible to exploit the advantages of traditional (or conventional) techniques and algorithms with analytical tool of artificial intelligent (AI) theory to generate a new algorithm of control known as hybrid control system (HCS). This offers a new dimension to process control performance in industry.

One essential process in industry is the chemical reactions taking place in reactors. An example is the waste water treatment. Wastewater from industrial process comes out as pollutants. Treating some of these pollutants is costly and difficult. Also, the characteristics of wastewater may change significantly with respect to industrial activities. Nevertheless, the most essential possibility of wastewater treatment process is to regulate the effectiveness of such harmful wastewater. Since the pH is the most important characteristic of wastewater pH-control to maintain desired level of wastewater concentration that is not harmful becomes worthwhile. This is known as neutralization.

Many different control algorithms and models have been developed and applied to wastewater treatment in chemical reactor when for instance conventional control techniques are applied to such process systems having kinetic reaction and thermodynamic interactions, adequate system performance are not provided and as such fails to compensate for the entire operating factors. Hence, the application of conventional proportional integral and derivative (PID) or fuzzy logic control (FLC) algorithm cannot provide or guarantee optimal performance as compared to a hybrid system such as PID and Fuzzy logic control.

In order to exploit the benefits provided by intelligent control system and to provide efficient and robust control performance of chemical process, a control technique that combines PID controller and FLC is developed for wastewater treatment in this paper.

II. REVIEW OF RELATED WORK

This paper examines the application of CSTR in industrial treatment of wastewater in terms of pH-regulation using different techniques. This is known as neutralization. Some research works have been presented in literature using some control approach to regulate the pH (acidity and alkalinity) of wastewater. In [6] the authors designed a Proportional Integral and Derivative (PID) algorithm using different tuning methods proposed in previous studies for pH neutralization process. The performances of the various approaches were examined in terms of peak overshoot and settling time and error indices such as Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral of Time weighted Absolute Error (ITAE). In [7], pH control process was developed so as to find the feasibility of applying advanced control strategy to it. The modeling of the pH process in continuously stirred tank reactor was presented. The objective of the pH control was to maintain the pH value of the process at desired value during transient operations by manipulating the alkaline flow rate. The study revealed that the performance of the system improved on application of advanced control schemes such as model reference adaptive controller, and Model Reference Adaptive Control (MRAC) with Fuzzy logic controller, MRAC with Neural network that required optimizing several process parameters. Experimental investigations to study the pH-control problems of industrial electroplating wastewater treatment plants were performed by [8]. It stated that conventional PID control system could handle most problems and disturbances during the normal operation of the water treatment. However, an innovative technique for treatment process known as Aquasil technology was used by the author to carry out the experimental investigation. It was found that the Aquasil technology proved to be more effective for a wide range of pH. A fuzzy logic control (FLC) system for pH process was developed by [9] to solve the problem of nonlinearity, which makes maintaining the desired transient response according to set pH value difficult to achieve. A model of pH neutralization process plant is developed by taking into consideration of the overall plant's dynamics [10]. It was found that the fuzzy system offered more efficient transient response than conventional controllers. A laboratory scale CSTR was fabricated and then a PID controller is developed for regulating the CSTR process in which acid-base reaction takes place [11]. The PID system was used to regulate pH of solution which was a neutralization process. The PID was able to control and maintain the pH precisely.

A. Performance Indices

The performance of a control system can be measured in terms of error indices such as Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE).

The peformance of the proposed system is examined in terms of ISE, IAE and ITAE. These performance indices are defined mathematically as given in Eq. (1), Eq. (2) and Eq. (3) [12]:

$$ISE = \int_0^\infty e^2(t)dt \tag{1}$$

$$IAE = \int_0^\infty |e(t)|\, dt \tag{2}$$

$$ITAE = \int_0^\infty t\,|e(t)|\, dt \tag{3}$$

The ISE focuses on the square of the error function and deals with both the positive and negative values of the error. IAE utilizes the size of the error and increases for either positive or negative error. ITAE deals with prolong transients and offers performance index that is more selective compared to ISE or IAE [13].

III. RESEARCH METHODOLOGY

Having studied various CSTR processes for pH-neutralization control, a hybrid intelligent control model that combines the algorithms of Fuzzy Logic Control and PID was designed with the Fuzzy Inference System (FIS) framework is proposed to improve response performance of the system in terms of rise time, settling time and percentage overshoot, as well as the error performance in PID and FPID.

A. Mathematical Modeling of pH Neutralization Process

A diagram model of a pH neutralization process for wastewater treatment is shown in* Figure 1. In this process, strong acid (HCl) and strong base (NaOH) of 1 molarity [6] are used.

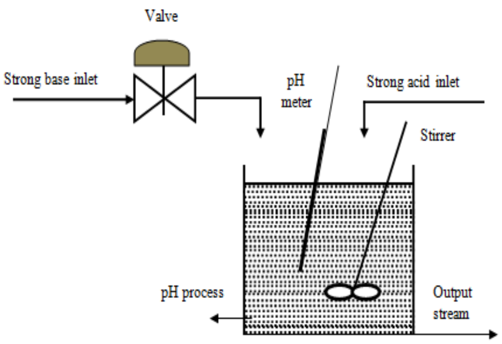

Figure 1: Diagram model of a pH process

Assuming no chemical reaction at given level, the equation for material balance can be expressed by:

[Rate of accumulation within vessel volume] =

[Inflow rate to the pH process]-[Outflow rate from the pH process] (3)

$$V\frac{dX}{dt} = U - FX \quad (4)$$

where V is the volume of the mixture in the pH process, X is the state variable of the nonlinear pH process, U is the pH process input flow rate, F is the pH output flow rate. The back titration curve for process flow is given by:

$$T_{(pH)} = X \quad (5)$$

In a chemical reaction, the components of the system for the back titration curve (TC) produce the non linearity of the process flow and can be represented by:

$$C_{TC} = \frac{A[pH] + \sum_{i=1}^{n} a_i[pH]C_i}{\sum_{i=1}^{n} a_i[pH]X_i} \quad (6)$$

where $a_i[pH]$ is the acid-base weighting factor (-1 for Strong acid and +1 for strong base), n is the number of ions present in the reactor, C_i ion concentration of the i^{th} kind of process flow, X_i is the concentration of the i^{th} kind of neutralization liquid. The value of pH is defined as the negative logarithmic value of the concentration of Hydrogen $[H^+]$ ions.

$$pH = -\log\left(H^+\right) \quad (7)$$

For the neutralization process

$$A[pH] = 10[-pH_{sv}] - 10[pH_{sv} - 14] \quad (8)$$

where pH_{sv} is the setpoint (or desired) value. In the neutralization process, the difference value between the actually measured pH and the set point value in line with the nonlinear conversion is given by:

$$Y = T(pH_{sv}) - T(pH) \quad (9)$$

The First order differential equation is given by Eq. (4) and since X is equal to T(pH), substituting into (4) gives:

$$V\frac{d[pH]}{dt} = U - F[pH] \quad (10)$$

Taking the Laplace transform of Eq. (10) and rearranging gives:

$$VspH(s) + FpH(s) = U(s) \quad (11)$$

Further rearrangement of Eq. (10) gives:

$$\frac{pH(s)}{U(s)} = \frac{\frac{1}{F}}{\frac{V}{F}s + 1} \quad (12)$$

where V/F is equal to the process time constant τ and 1/F is the process gain, K.

The pH process is a first order system with time delay due to pipe line and detection process for the measuring instrument (sensor). Hence it takes the general transfer function model of first order plus time delay (FOPTD) given by:

$$G(s) = \frac{Ke^{-T_D s}}{\tau s + 1} \quad (13)$$

where $e^{-T_D s}$ is the time delay.

Substituting parameters obtained from real time experiments conducted in [13] which was applied in [6], with K = 0.276, $\tau = 3.2$, and T_D = 5.005, Eq. (13) becomes:

$$G(s) = \frac{0.276e^{-5.005s}}{3.2s + 1} \quad (14)$$

Therefore Eq. (14) is the established transfer function model for a pH neutralization process for wastewater treatment considered.

B. *Existing Study Architecture*

The existing system structure is shown in Fig. 2. The architecture represents a continuous time control system that uses a PID control model to improve the response performance of the system. The structure shows a feedback continuous time PID control model in the forward path with pH neutralization process (plant)

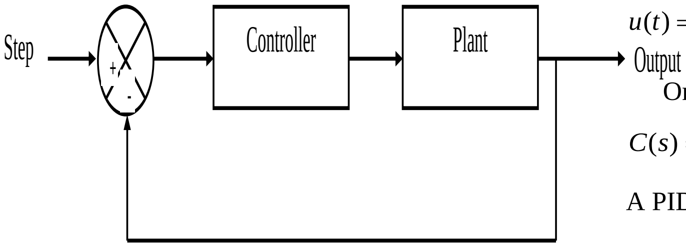

Figure 2: Existing System Architecture

The continuous time PID controlled pH neutralization control process offers improved performance in terms of robustness. However, the problem with a PID model is that its performance is seriously affected by perturbation and nonlinearity effect associated with industrial processes. For this reason, intelligent models are increasingly being proposed and demanded in industries because of their ability to overcome the effect of nonlinearity.

C. *Proposed System Architecture*

The proposed control algorithm for an industrial chemical process which is a pH neutralization process in CSTR is given by the combination of fuzzy algorithm, PID algorithm and Fuzzy PID (FPID) algorithm. Initially, the parameters (or gains) of the PID control algorithm are obtained by the means of tuning using error signal. The gains of PID are used to tune fuzzy PID. Figure 3 shows the proposed system architecture.

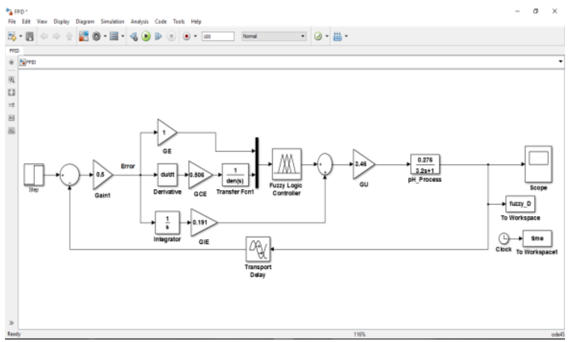

Figure 3: Hybrid Model of the proposed pH process with Fuzzy-PID

D. *Analysis of Proposed System*

In order to analyze the proposed system, the various Models that make up the control loop are designed.

1) Proportional Integral Derivative Control Model

Proportional Integral Derivative (PID) control model has been well implemented in almost every industrial process due to its simplicity of design and robustness. This model is largely common because it is able to provide good response characteristic for a closed loop system. A PID controller offers a proportional action to control error, an integral action to control error and a derivative action to control error The basic PID control law is represented by:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (15)$$

Or in Laplace transform as:

$$C(s) = \frac{U(s)}{E(s)} = K_p + K_i \frac{1}{s} + K_d s \qquad (16)$$

A PID algorithm with low pass filter is developed and is given by:

$$C(s) = k_p + K_i \frac{1}{s} + K_d s \times \frac{1}{Tfs+1} \qquad (17)$$

In order to design the PID controller in MATLAB, the following steps are followed:

The CSTR transfer function is generated in MATLAB command window. A PID tuner is opened as shown in Fig. 4

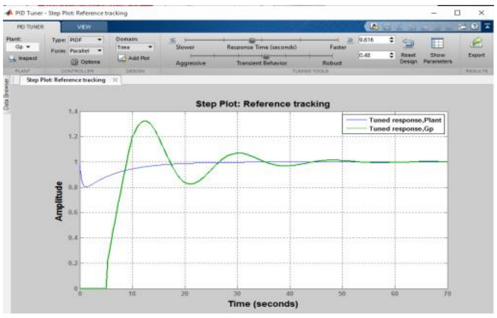

Figure 4: MATLAB PID GUI Tuner

The transfer function in Eq. (14) known as the plant is imported and then faster and robust tuning is carried out to obtain the appropriate gains $k_p = 3.46$, $k_i = 0.661$, and $k_d = 0.0408$.

The designed PID compensator with low pass filter, C is exported to the MATLAB command window as presented below:

Hence, the continuous-time PID controller in parallel form designed in this paper is given by:

$$\mathrm{C(s)} = 3.46 + \frac{0.661}{\mathrm{s}} + \frac{1.75\mathrm{s}}{0.0408\mathrm{s}+1} \qquad (18)$$

The Simulink model of pH process compensated with PID algorithm is shown in the MATLAB programme created using the extension file (m-file) is given

This Matlab code simulates a PID controller for a first order time delay system
*% G(s) = (K*e(-theta*s))/(T*s+1)*

clear all;
clc;

```
T = 3.2; K = 0.276; theta = 5.005; % System Parameters
refe = 1;            % Reference to follow
Tf = 1000;           % Simulation time
yold = 0;yold1=0;
yp = []; ys_prime = [];
er = refe;      % Error (Initial error = Reference)
er1 = 0;        % First derivative of error
er2 = 0;        % Second derivative of error
eold = refe; eold2 = 0;
dt = 1;
for i=1:dt:Tf
dtspan = [ii+dt];
   eold2 = eold ;
eold = er;
er = refe - yold;
   er2 = er + eold2 - 2*eold;
   er1 = er - eold;
```

In Fig. 5 shows the PID control model design in MATLAB/Simulink, containing the PID controller, the transfer function for the process, the scope and transport delay.

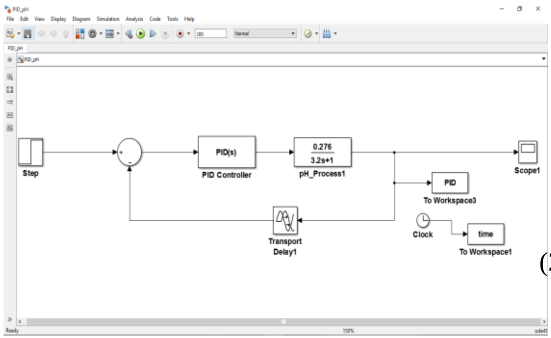

Figure 5: Simulink Model for PID Control Model

The block diagram of pH process for PID was modeled in Simulink. The first input to the summer or summing point (that is the block with ± sign) is the set pH value (represented by the step block) and it is the desired or set pH value at which the pH process is expected to run to or achieved. The second input to the summer is the feedback signal, which is the current pH value at the output of the pH process which is measured or captured by a feedback sensor.

2) Fuzzy Logic Control Model

The steps listed below followed for designing and modeling of the Fuzzy Logic Control (FLC).

1) The objectives and specifications are defined. This involves determining what to control, what to do to control the system and the kind of output (or response). Expected.
2) The input and output relationships are established and a minimum number of variables selected for input to the fuzzy logic system (for example, error and time derivative of error).
3) The problem to be controlled is broken down into a series of IF and THEN using the Fuzzy Logic rule-based structure. These rules defined the desired output response of the system for a given input condition.
4) The member functions of the fuzzy logic are created which help to define the values of input-output terms used in the rules.
5) Simulation of the system is conducted after the construction of the fuzzy logic system.
6) The system is tested, the results evaluated, the rules and membership functions tuned and re-tested until satisfactory results were obtained.

A typical fuzzy logic control system has at least two inputs and output [14]. Fuzzy inference System (FIS) maps inputs-outputs using the member functions. A membership function (MF) is a shape that defines how each point in the input crisp value is mapped to a degree of MF [14] between 0 and 1. In this design, the input and output is defined as follows: since Fuzzy logic control system needs at least two inputs and output, the first input will be the error (E) while the second input is the change in the error $(\mathrm{DE}(s))$ and the control output U(s) of the fuzzy output (Y(s)). The linguistic variable levels are assigned as: Negative (NE), zero (ZE), and Positive (PO). Similarly, the fuzzy set for error change (DE) is presented as NE, ZE, and PO. The ranges of these inputs are from -1 to 1 and -1 to 1 respectively. The equation establishing these are expressed given by:

$$\mathrm{E}(s) = \mathrm{R}(s) - \mathrm{Y}(s) \quad (19)$$

$$DE(s) = sE(s) - \mathrm{E}(0) \quad (20)$$

Assuming zero initial condition and substituting Eq. (18) into Equation (19) gives:

$$DE(s) = s(R(s) - \mathrm{Y}(s)) \quad (21)$$

In designing a fuzzy logic control model, a fuzzy inference system (FIS) of fuzzy logic tool is used. For the building, editing and monitoring fuzzy systems five basic tools representing the algorithm are used as shown in figure 6 and outline as follows: a) Editor to determine the fuzzy inferential system FIS (called FIS editor b) Member function (MF) editor c) Rule editor d) Rule viewer and e) Surface viewer.

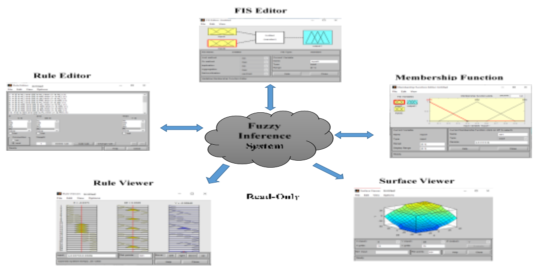

Figure 6: Five basic tools representing the algorithm

3) Design of the Proposed Fuzzy-PID Compensator

In the designing the Fuzzy-PID, the inputs to the FLC still remains the error (E) and the time derivative of the error (or change in error), dE/dt while the outputs in this case are the gain parameters K_p, K_i, and K_d. the structure of Fuzzy-PID control system is a two input-three output Structure. For obtaining the range or the universe of discourse of the input and output membership functions, the PID control algorithm is tuned using the conventional Zeigler Nichols Method of the MATLAB PID tuner.

In the process of pH concentration control, the maximum error reached could be 100% (or unity) and accordingly the universe of discourse for the fuzzy input error (E) is fixed as: (-1, 1) and the change in error is also chosen with the same range, that is: (-1, 1). In order to integrate the PID with the fuzzy system, scaling factors are determined. The scaling factors GE, GCE, GIE and GU from K_p, K_i, and K_d gains used by the conventional PID compensator. Comparing the expression of the PID and the proposed Fuzzy-PID compensator, the following expressions are established:

$$GE = 1 \quad (22)$$

$$GCE = GE \times \frac{K_d}{K_p} \quad (23)$$

$$GIE = GE \times \frac{K_i}{K_p} \quad (24)$$

$$GU \times GE = K_p \quad (25)$$

Substituting the values of the PID gains into the equations above gives:

$$GCE = 1 \times \frac{1.75}{3.46} = 0.506$$

$$GIE = 1 \times \frac{0.661}{3.46} = 0.191$$

$$GU = \frac{3.46}{1} = 3.46$$

IV. Results and Disscussion

The results of the simulations carried out in MATLAB/Simulink environment for pH concentration control system whose mathematical models, representing the dynamic of the process, are combined with Proportional Integral Differential (PID) controller (compensator), Fuzzy Logic Control (compensator), and Fuzzy-PID control model (compensator) are presented. The results are presented in terms of unit step responses. A step response represents the output of a desired value of an industrial or chemical process expressed as unity (or 100%) such that the control model when implemented as part of the system is expected to ensure that the output of the process reaches close or track this predetermined value and maintained it with negligible error. The step responses to a unit step input (representing 100% output efficiency) are presented below:

1. The step response of pH concentration process without a compensator or control model
2. The step response of pH concentration process compensated with PID control Model
3. The step response of pH concentration process compensated with Fuzzy-PID control model

The various simulation results are subsequently presented as follows:

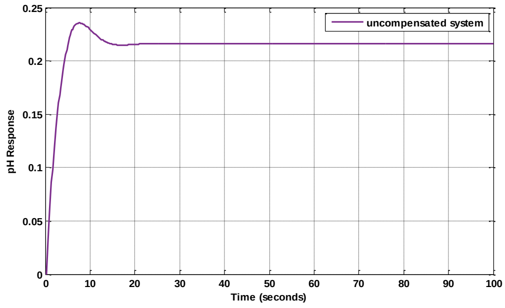

Figure 7: Unit step Response of uncompensated pH

In Fig. 7 the result shows the performance of uncompensated pH control procese that is, without a control model. It is showned that the response performance is not suitable in the pH process plant due to the fact that it is highly affected by uncertainity , nonlinearity and pertubation.

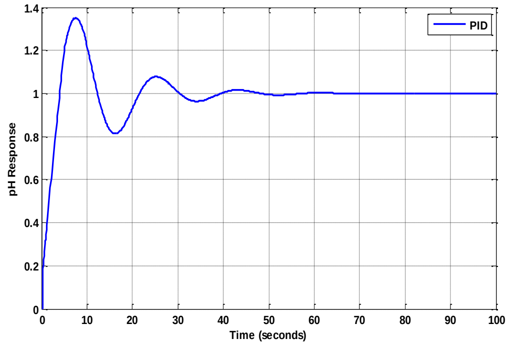

Figure 8: Step response of PID compensated pH process

Figure 8 step response has a PID Control Model of a compensator. It is observed that the step responses are dynamical responding to the set point signal. Here the uncertainty and perturbation reduce due to the PID Controller. The response signal is still slightly affected by noise and other factors in the system.

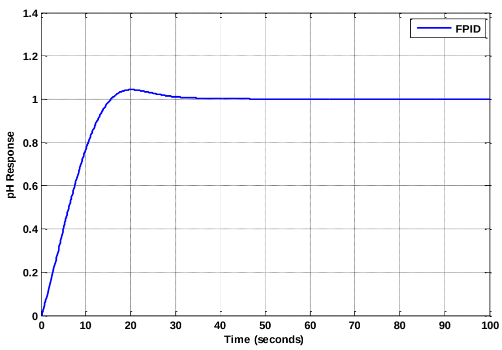

Figure 9: Step response of Fuzzy-PID compensated pH process

The result in Fig. 9 shows that the Fuzzy-PID known as FPID hybrid control model was able to address and handle the challenges of nonlinearity and perturbation. The system dynamic responds were better suitable for the pH control plant to function. A remark for each simulation condition is presented in Table 1.

TABLE I. REMARK FOR EACH OF THE SIMULATION RESULT FOR COMPENSATED AND UNCOMPENSATED MODEL

System State	Remark with respect to unit step input
Uncompensated	The system could not reach the desired pH value (that is, 1 or 100%). Hence, it is unsatisfactory in this case
PID	The system was able to track or reach the desired pH value but showed high possibility of instability due to high overshoot. Hence it is unsatisfactory.
Fuzzy-PID (Proposed System)	The system was able to track or reach the desired pH value with high stability showing very little (or no steady state error).

A. Performance of Analysis in Terms of Unit Step Input

This subsection presents the performance analysis of the various simulations considering Fig. 5-7. The step response performance parameters are given in continuous time domain and are presented in Table 1I.

TABLE II. PERFORMANCE ANALYSIS OF SYSTEM RESPONSE TO UNIT STEP INPUT

System state	Rise time (s)	Peak Time (s)	Settling time (s)	Overshoot (%)	e_{ss}
Uncompensated	3.65	7.70	12.37	8.90	0.76
PID	3.28	7.60	37.04	35.20	0
Fuzzy-PID	11.06	20.22	26.88	4.34	0

Note: e_{ss} means Steady State Error.

The result obtained in Table 2 can be further analyzed into various state responses. It is showed that the Overshoot obtain is 4.34% with steady state error of 0.

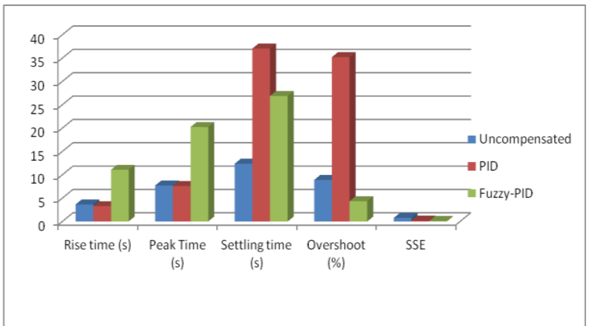

Figure 10: Analyzed Response of System State

B. Validation of Fuzzy-PID Unit Step Response for varying pH value

In order to validate the performance of the proposed Fuzzy-PID control algorithm, simulations were further carried out setting the desired pH value at 5, 7, 9 which represent acid, neutral, and base medium respectively. The choice of these values was necessitated because pH above 9 and pH below 4 are considered to be harmful to the surroundings [6]. The essence of this was to study the effectiveness of the proposed system in maintaining effective output at any desired pH value

C. Performance Responses for pH Values in Acid, Base and Neural using PID and FPID Control Model

Table 3 through Table 5 are the numerical analysis of the performance indices ISE, IAE and ITAE and there corresponding simulation plots for different pH media –acid medium of pH = 5, neutral medium of pH = 7 and base (or alkaline) medium of pH = 9 are shown in Fig. 11 through Fig. 13 for PID control and FPID control pH neutralization process.

TABLE III. ERROR PERFORMANCE RESPONSES FOR PH VALUE-5: ACID PH- 5

Control Model	ITAE	ISE	IAE
PID	39.61	164.70	51.58
FPID	28.86	71.75	39.31

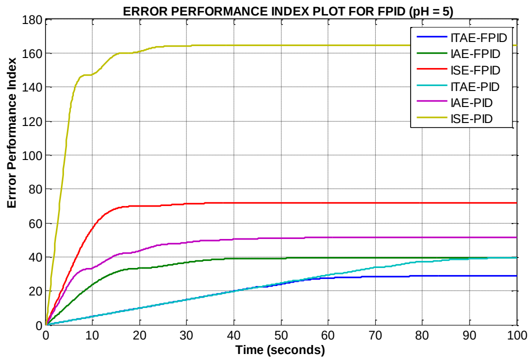

Figure 11: Error Performance Index PID, and FPID, pH-5

TABLE IV ERROR PERFORMANCE RESPONSES FOR PH VALUE-7NEURAL MEDIUM PH VALUE – 7

Control Model	ITAE	ISE	IAE
PID	41.37	322.90	72.20
FPID	34.11	141.80	56.47

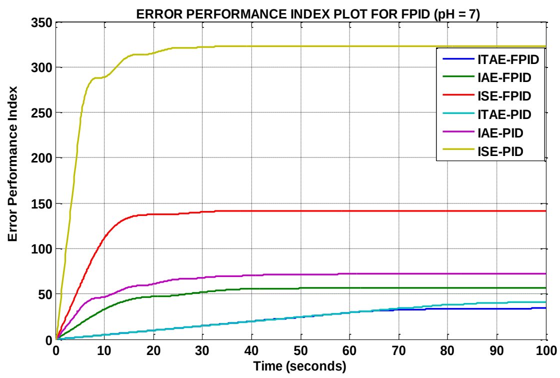

Figure 12: Error Performance Index PID, and FPID, pH-7

TABLE V ERROR PERFORMANCE RESPONSES FOR PH VALUE-9 NEURAL MEDIUM PH VALUE – 9

Control Model	ITAE	ISE	IAE
PID	42.75	533.70	92.83
FPID	36.53	234.80	73.09

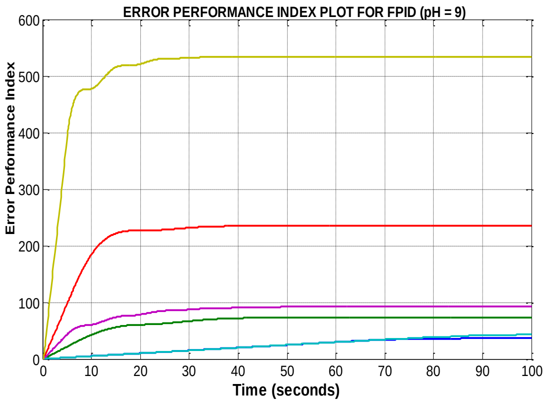

Figure 13: Error Performance Index PID, and FPID, pH-9

The performance indices analyses in Table 3 through Table 5 showed that in the three media considered, the error performance indices of FPID control pH neutralization process were better than that of PID control system. This is obvious looking at the numerical values of ISE, IAE and ITAE in the various media of acid, neutral and base for PID controlled and FPID controlled pH neutralization process. That is, least error performance indices were obtained using FPID controller to regulate the pH neutralization process. Hence, the FPID provided more efficient and robust performance in terms of error handling which is a measure of the deviation of actual pH value from set or reference pH value.

V. CONCLUSION

The paper has presented an intelligent control model in performance improvement of industrial process for pH regulation process. A mathematical model of a pH neutralization process for wastewater management was obtained. The equations for pH neutralization process were modeled in MATLAB/Simulink environment to study the dynamic performance response of the process when no computational model was applied has been introduced. Simulation was initially carried out for uncompensated condition and the result showed that step response performance to unit step input was largely unsatisfactory as the response obtained was far less than the desired pH value. Hence, a computational model such the PID, Fuzzy and FPID for a compensator that combines proportional integral and derivative (PID) actions was developed using the MATLAB/Simulink PID tuning tool. Simulation was conducted considering only the PID computational compensation model. The result obtained indicated improvement from the uncompensated process with the PID compensator ensuring that the output attained the desired pH value with respect to unit step input. However, the PID performance needed to be improved with respect to the overshoot performance. A compensator model that combined PID computational gains and Fuzzy Logic intelligent algorithm called Fuzzy-PID (FPID) was proposed the result showed that the FPID provided better stability and overshoot performance than conventional PID control system.

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