ENHANCEMENT OF H2S GAS SWEETENING SEPARATOR USING MIMO FUZZY LOGIC CONTROLLER

MUHAMMAD M.A.S. MAHMOUD

Al Hosn Gas Co. ADNOC Group OPCPO,s, UAE
E-mail: Muhammad.Manar@alhosngas.com

Abstract- Natural gas sweetening process is a controlled process that must be done at maximum efficiency and with the highest quality. In this work, due to complexity and non-linearity of the process, the H2S gas separation and the intelligent fuzzy controller, which is used to enhance the process, are simulated in MATLAB, A new design of fuzzy control for Gas Separator is introduced. The design based on the utilization of linear state-estimation to generate the internal knowledge-base that stores input-output pairs. This collection of pairs is then used to build a feedback fuzzy controller. The proposed closed-loop fuzzy control system maintains the system asymptotically-stability while it enhances the system time response to achieve better control of the concentration of the output gas from the tower. Simulation studies are carried out to illustrate the Gas Separator system performance.

Keywords- Gas Separator, Gas Sweetening, Intelligent Controller, Fuzzy Control. .

I. INTRODUCTION

Hydrogen sulfide in sour natural gas causes corrosion in the equipment, reduces the economic value of gas, pollutes the environment and its smell brings poisoning and at relatively low concentration has lethal effect; therefore, it is necessary to separate it from the sour gas. If the concentration of H2S in the natural gas is more than 4 PPM, it will be acid gas. To separate acid gas, such as hydrogen sulfide, from natural gas, towers tray and solutions such as amines are used in the gas industries. Hydrogen sulfide is absorbed along with chemical reaction and this reaction has two positive effects on the absorption intensity; first, the absorption rate is increased by reduce of the equilibrium partial pressure, and second, it increases the mass transfer coefficient, so arise the absorption intensity. Various models are presented for simulation of the absorption processes with chemical reaction. (Jaswon MA and Smith W) presented the first dynamic model of gas absorption towers. Dynamic model which was obtained by (Jaswon MA and Smith W) had complex mathematical equations, was analyzed and evaluated by (Tommasi G and Rice P) and Rice and they suggested a new solution for unknown boundary conditions of those complex equations. (Liapis AI and Macavoy TJ) presented a linearization method to overcome the slow convergence of (Jaswon MA and Smith W) method. (Bardley KJ and Andre H) presented another dynamic model for gas absorption tower in which a particular method is used to calculate the amount of mass transfer. (Lakshmanan C and Potter OE) presented a dynamic model of time provided for systems with different directions currents, which was used for the modeling of the absorption packed columns. (Rahimpour MR, Fathikalajahi J and Jahanmiri A) had studied simulation and optimization of the reverted gas into the methanol reactor. (Ghader S and Fathikalajahi J) presented optimal values for feed temperatures (operating point) reactor feed to methanol reactor which was simulated. (Løvik I) obtained optimal value for temperature of the cooling water and amount of reverted gas into reactor, in addition to simulated methanol synthesis reactor. (Doyle F and Balasubramhanya LS) presented a controller based nonlinear model for Ethyl Acetate Reactive distillation. (Kumar A and Daoutidis P S) presented a framework of algebraic differential equations for control continuous reactive distillation tower. (Fatima Barcel) used a fuzzy control technique to control continuous distillation tower. (Jeen Lin and Ruey-Jing Lian) presented continuous fuzzy logic and neural network controller for systems with multiple inputs and outputs. (Harun Taskin) ., presented a fuzzy logic controller to improve the dynamic operation of catalytic cracking unit.

A major direction in systems engineering design has been focused on the use of simplified mathematical models to facilitate the design process. This constitutes the so-called model-based system design approach, an overview of the underlying techniques can be found in (M. S. Mahmoud) .

Most of the available results have thus far overlooked the operational knowledge of the dynamical system under consideration. On the other hand, a knowledge-based system approach (K. M. Passino, and S. Yurkovick) has been suggested to deal with the analysis and design problems of different classes of dynamical systems by incorporating both the simplest available model as well as the best available knowledge about the system. For single physical systems, one of the earlier efforts along this direction has been on the development of an expert learning system; see (M. S. Mahmoud, S.Z. Eid) ,(M. S. Mahmoud, S. Kotob), (M. S. Mahmoud, A. A. Abou-Elseoud) and (L. X Wang) and their references. An alternative approach

has been on integrating elements of discrete event systems with differential equations (C. C. Lee) .

A third approach has been through the use of fuzzy logic control by successfully applying fuzzy sets and systems theory (Wang, Li-Xin) . In the cases where understood there is no acceptable mathematical model for the plant, fuzzy logic controllers (M. Sugeno, and G.T. Kang) are proved very useful and effective. They are generally base on using qualitative rules of thumb, that is, qualitative control rules in terms of vague and fuzzy sentences. It has been pointed out (Takagi, and M. Sugeno) that fuzzy control systems possess the following features:

- Hierarchical ordering of fuzzy rules is used to reduce the size of the inference engine.

- Real-time implementation, or on-line simulation, of fuzzy controllers can help reduce the burden of large-sized rule sets by fusing sensory data before imputing the system's output to the inference engine.

This paper contributes to the further development of fuzzy control techniques by presenting a new approach to fuzzy control design for a gas separator. It provides a new and efficient procedure to construct the inference engine by incorporating a linear state-estimator in generating and storing input-output pairs. This collection of pairs is then utilized to build a feedback fuzzy controller. By fine-tuning of the controller parameters, it is shown that the gas separator system has always a guaranteed stability. Numerical simulation of a six-order gas separator is carried out and the obtained results show clearly that the proposed estimator-fuzzy controller scheme yields excellent performance.

II. A GAS SEPARATOR SYSTEM

2.1. A brief Account

Separation processes play an important role in most chemical manufacturing industries. Streams from chemical reactors often contain a number of components; some of these components must be separated from the other components for sale as a final product, or for use in another manufacturing process. A common example of a separation process is gas absorption (also called gas scrubbing, or gas washing) in which a gas mixture is contacted with a liquid (the absorbent or solvent) to selectively dissolve one or more components by mass transfer from the gas to the liquid. Absorption is used to separate gas mixtures; remove impurities, contaminants, pollutants, or catalyst poisons from a gas; or recover valuable chemicals. In general, the species of interest in the gas mixture may be all components, only the component(s) not transferred, or only the component(s) transferred. Absorption is frequently conducted in trayed towers (plate columns), packed columns, spray towers, bubble columns, and centrifugal contactors. A trayed tower is a vertical, cylindrical pressure vessel in which vapor and liquid, which flow counter-currently, are contacted on a series of metal trays or plates; see Fig. 1. Components that enter the bottom of the tower is the gas feed stream are absorbed by the liquid stream, that flows across each tray, over an outlet weir and into a downcomer, so that the gas product stream (leaving the top of the tower) is more pure. A Simplified model of the separator presented in (Seyed Besharat Anjamrooz) shall be used as a typical model for our study.

2.2. Assumptions and Definitions

The basic assumptions used are:

A1. The major component of the liquid stream is inert and does not absorb into the gas stream.

A2. The major component of the gas stream is inert and does not absorb into the liquid stream.

A3. Each stage of the process is an equilibrium stage, that is, the vapor leaving a stage is in thermodynamic equilibrium with the liquid on that stage.

A4. The liquid molar holdup is constant.

We can now introduce the following variable definitions:

L = moles inert liquid per time: = liquid molar flow rate.

V= moles inert vapor per time: =vapor molar flow rate

M= moles liquid per stage: =liquid molar holdup per stage.

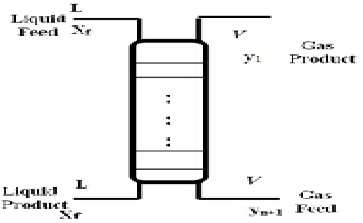

Fig.1. Gas Separator column, n stages

The concept of an equilibrium stage is important for the development of a dynamic model of the absorption tower. An equilibrium stage is represented schematically in Fig. 2. The total amount of solute on stage j is the sum of the solute in the liquid phase and the gas phase (that is, M xj + W yj). Thus the rate of change of the amount of solute is d(M xj + W yj)/dt and the component material balance around stage j can be expressed as:

$$\frac{d(Mx_j + Wy_j)}{dt} = Lx_{j-1} + Vy_{j+1} - Lx_j - Vy_j$$

$$\frac{dMx_j}{dt} \cong Lx_{j-1} + Vy_{j+1} - Lx_j - Vy_j \qquad (1)$$

Where, we assumed that in accumulation, liquid is much more dense than vapor. Under assumption A4), then (1) simplifies into:

$$\frac{dx_j}{dt} \cong \frac{L}{M} x_{j-1} + \frac{V}{M} y_{j+1} - \frac{L}{M} x_j - \frac{V}{M} y_j \qquad (2)$$

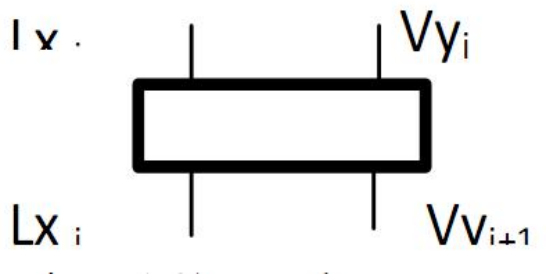

Fig.2. A typical gas absorption stage.

Under assumption A3), we let

$$y_j = d\ x_j \qquad (3)$$

which expresses a linear relationship between the liquid phase and gas phase compositions at stage j with d being an equilibrium parameter. Using (3) into (2) and arranging we get:

$$\frac{dx_j}{dt} = \frac{L}{M}x_{j-1} - \frac{(L+Vd)}{M}x_j - \frac{Vd}{M}x_{j+1} \qquad (4)$$

For n-stage gas separator, (4) is valid for j =2,…,n-1. At the extreme stages, we have:

$$\frac{dx_1}{dt} = -\frac{(L+Vd)}{M}x_1 - \frac{Vd}{M}x_2 + \frac{L}{M}x_f \qquad (5)$$

$$\frac{dx_n}{dt} = -\frac{(L+Vd)}{M}x_n + \frac{L}{M}x_{n-1} + \frac{V}{M}y_{n+1} \qquad (6)$$

where x_f and y_{n+1} are the known liquid and vapor feed compositions, respectively. On combining (4-6), we reach the state-space model:

$$\dot{x}(t) = A\,x(t) + B\,u(t)$$

$$y(t) = C\,x(t) \qquad (7)$$

where A an (nxn) system matrix with a tridiagonal structure, B is an (nxm) input matrix and C is an (nxp) output matrix given by (Equation 8- a, b &c respectively):

$$A = \begin{bmatrix} -\frac{L+M}{M} & \frac{Vd}{M} & 0 & 0 & 0 & 0 & \cdots & 0 \\ \frac{L}{M} & -\frac{L+Vd}{M} & \frac{Vd}{M} & 0 & 0 & \cdots & & 0 \\ 0 & \frac{L}{M} & -\frac{L+Vd}{M} & \frac{Vd}{M} & 0 & \cdots & & 0 \\ 0 & & \ddots & & & & & 0 \\ \vdots & & & & & & & \vdots \\ 0 & & & & & & \frac{L}{M} & -\frac{L+Vd}{M} \end{bmatrix} \qquad (8\text{-a})$$

$$B = \begin{bmatrix} \frac{L}{M} & 0 \\ 0 & 0 \\ \vdots & \vdots \\ \vdots & \vdots \\ \vdots & \vdots \\ \vdots & \vdots \\ 0 & \frac{V}{M} \end{bmatrix} \qquad (8\text{-b})$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \qquad (8\text{-c})$$

A MATLAB program is written to simulate the gas separator system. Different positive and negative step input are applied to estimate the outputs. The results of two cases are illustrated in Fig. 8 and Fig. 9. The tracking behavior of the outputs is shown.

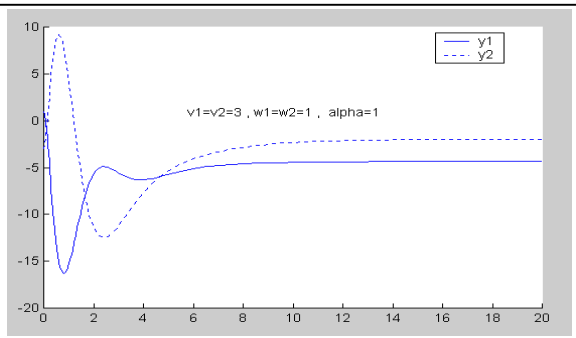

Fig.8. Output Response with positive input signal

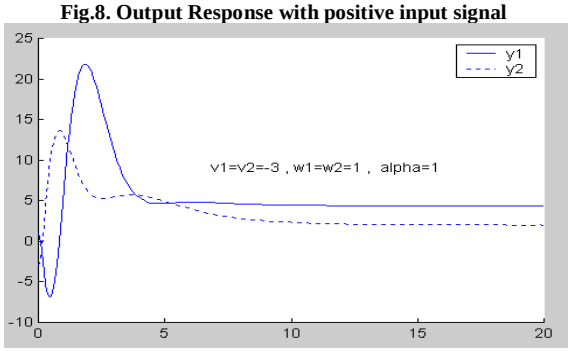

Fig.9. Output Response with negative input signal

III. FUZZY CONTROLLER DESIGN

Following (Takagi, and M. Sugeno) , the design of a fuzzy controller can be implemented by the following steps:

Step1: Supposed that the output y (t) takes values in internal U = [α, β] $\subset$ R. Define 2N+1 fuzzy A^1 in U that are normal, consistent and complete with the triangular membership functions shown in Fig. 7. That is, we use the N fuzzy sets A^1, ---, A^N to cover the negative interval [α, 0), the other N fuzzy sets A^{N+2},---, A^{2N+1} to cover the positive interval (0, β], and choose the center x^{N+1} of fuzzy set A^{N+1} at zero.

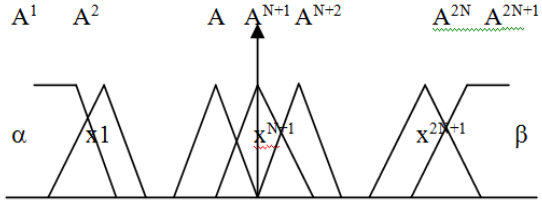

Fig.7. Membership functions for the fuzzy controller.

Step 2: Consider the following 2N+1 fuzzy IF-THEN rules:

IF y is Al, THEN u is Bl (10)

Where l = 1, 2, ---, 2N+1, and centers ~~y-l~~ of fuzzy set Bl are chosen such that,

$$\overline{yl} \begin{cases} \leq 0 & \text{for } l = 1,\text{---}, N \\ = 0 & \text{for } l = N+1 \\ \geq 0 & \text{for } l = N+2,\text{---}, 2N+1 \end{cases} \qquad (11)$$

Step 3: Design the fuzzy controller from the 2N+1 fuzzy IF- THEN rules (10) using product inference engine, singleton fuzzifier and center average defuzzifier; that is, the designed fuzzy controller is

$$v = -f(y) = \frac{\sum_{l=1}^{2N+1} y^{-}\mu_A^l(y)}{\sum_{l=1}^{2N+1} \mu_A^l(y)} \qquad (12)$$

Where μAl(y) are shown in Fig. 7 and y 1 satisfy $\overline{y}$ (11).

To estimate the range of the input-output pairs {v_i, y_i}, full order estimator (L. X Wang) can be used.

IV. SIMULATION STUDIES AND RESULTS

Consider H2S sweeting gas separator system with the following typical parameters: L=100, M=250, V=120 and d=0.6. Thus,

$$\frac{L+Vd}{M} = -0.688 \qquad (14)$$

$$\frac{L}{M} = 0.4 \qquad (15)$$

$$\frac{Vd}{M} = 0.288 \qquad (16)$$

$$\frac{V}{M} = 0.48 \qquad (17)$$

From the input-output pair obtained, the behavior of the system is examined and the ranges of its outputs (controllers' inputs) are predicted. Fig. 10 illustrates a block diagram of the gas separator and the fuzzy controller array. To control the response of the gas separator, the range of linguistic values of the output of each feedback fuzzy controller is tuned between (– 3) and (3). Comparison between the output response with fuzzy controller (when the number of linguistic values of the controller input – output pair is three) and without controller is illustrated in Fig.11(a,b) and Fig.12(a,b). In Fig.11(a,b), the controller is tuned to interfere the natural decay of the system. In Fig.12(a,b) , the fuzzy controller is adjusted to improve the response of the gas separator. It is noted that the response of controlled system has less overshoot, less steady state error and faster compared to the uncontrolled system.

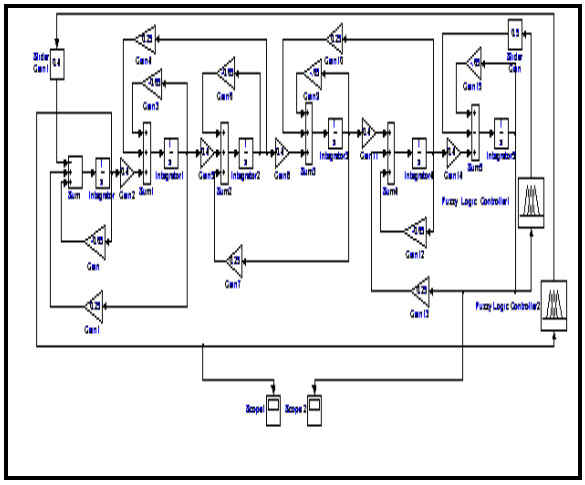

Fig. 10: Block Diagram of gas separator system and the fuzzy controllers

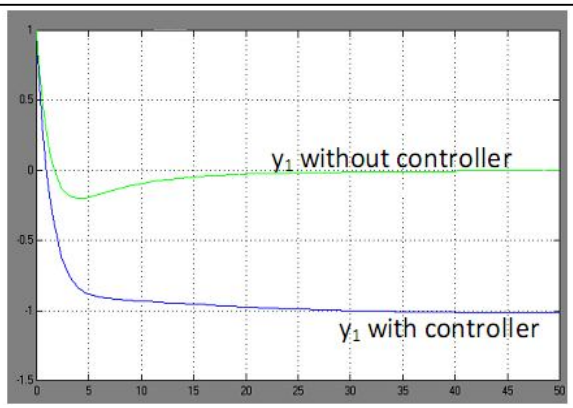

Fig .11 (a) The controller is tuned to interfere the natural decay of the system (y1-Response).

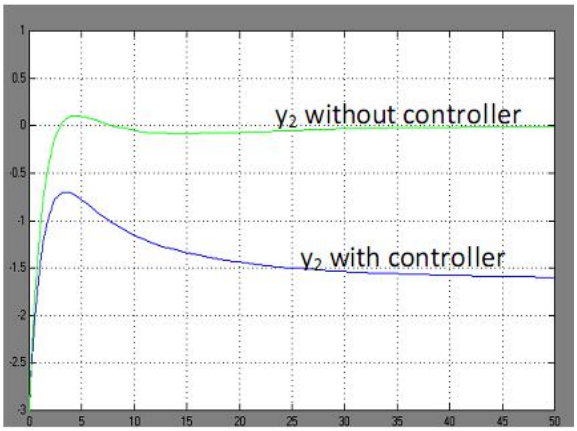

Fig .11 (b) The controller is tuned to interfere the natural decay of the system (y2-Response).

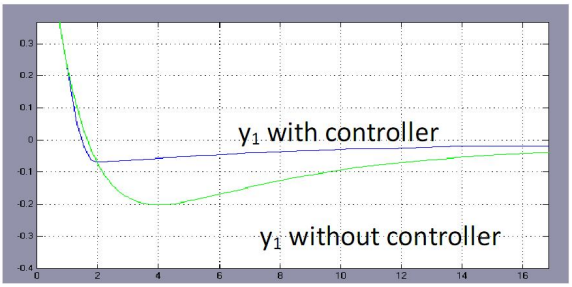

Fig .12.(a) The controller is tuned to improve the response of the system (y1-Response)

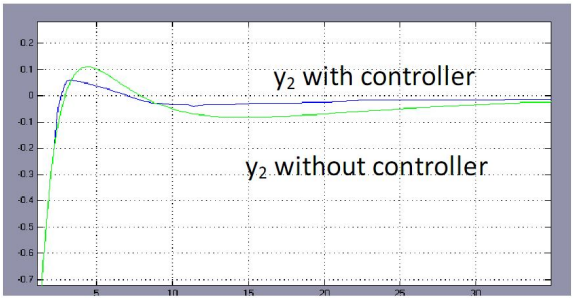

Fig .12 (b) The controller is tuned to improve the response of the system (y2-Response)

CONCLUSIONS

This paper has presented a new fuzzy control for a H_2S gas Sweetening separator system. The simulation results have shown that the controller guarantees

well-damped behavior of the controlled separator system and provide reasonable tuning for the natural decay of the system.

ACKNOWLEDGMENT

I'd like to appreciate the support of the Al Hosn Gas Co, PhD Council and Project Department, to publish this paper

REFERENCES

[1]. Jaswon MA and Smith W, Countercurrent Transfer processes in the Non-steady state. Proceedings of the Royal Society of London 225A 226-244 ,1954.
[2]. Tommasi G and Rice P , "Dynamic of Packed Tower distillation", Industrial & Engineering Chemistry Process Design and Development 9 234-243 ,1970.
[3]. Liapis AI and Macavoy TJ , "Transient solution for a class of Hyperbolic counter-current distributed Heat and Mass Transfer systems", Transactions of the Institution of Chemical Engineers 59 89-94 ,1981.
[4]. Bardley KJ and Andre H , "A Dynamic Analysis of a packed gas Separator", Canadian Journal of Chemical Engineering 50 528-533, 1972.
[5]. Lakshmanan C and Potter OE, "Cinematic Modeling of Dynamics of Solids Mixing in Fluidized Beds", 26(2) 292-296, 1987.
[6]. Rahimpour MR, Fathikalajahi J and Jahanmiri A , "Selective kinetic Deactivation Model for Methanol Synthesis from Simultaneous Reaction Of Co2 and Co with H2 on a commercial copper / zinc oxide catalyst", The Indian Journal of Chemical Engineering 76 153-761, 1998.
[7]. [Ghader S and Fathikalajahi J "Simulation of Methanol synthesis Reactor of shiraz petrochemial plant", MSc thesis Departmen of Chemical Engineering, Shiraz University, Iran(2000)..
[8]. Løvik I , "PhD Thesis", Norwegian University of Science and Technology, Department of Chemical Engineering, 2001.
[9]. Doyle F and Balasubramhanya LS , "Nonlinear model-based control of a batch reactive distillation column", Journal of Process Control 10 209-218 , 2000.
[10]. Kumar A and Daoutidis P , "A DAE framework for modeling and control of reactive distillation columns, in Symposium on Dynamics and Control of Chemical Reactors, Distillation Columns, and Batch Processes", IFAC, 1995.
[11]. Fatima Barcelo Rico, Jose M Gozalvez-Zefrilla, Jose LuisDiez and Asuncion Santafe-Moros, "Modeling and Control of a Continuous Distillation Tower through Fuzzy Techniques, Chemical Engineering Research and Design" 89 107-115, 2011.
[12]. Jeen Lin and Ruey-Jing Lian , "Hybrid Fuzzy-logic and Neural Network Controller for MIMO Systems", Mechatronics 19 972-986 ,2009.
[13]. Harun Taskin, Cemalettin Kubat, Ozer Uygun and Seher Arslankaya , Fuzzyfcc: "Fuzzy Logic Control of a Fluid Catalytic Cracking Unit (FCCU) to Improve Dynamic Performance, Computers and Chemical Engineering "30 850-863, 2006.
[14]. M. S. Mahmoud, "Computer-Operated Systems Control", Marcel Dekker Inc., New York, 1991.
[15]. C. C. Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Parts I& II", IEEE Systems, Man and Cybernetics, Vol. 20, No.2, March/April 1990, pp.404-435.
[16]. M. S. Mahmoud, S.Z. Eid and A .A. Abou-Elseoud, "A Real Time Expert System for Dynamical Processes", IEEE Transactions Systems, ManandCybernetics,Vol.SMC-19,No.5, September/October 1989, pp. 1101-1105.
[17]. M. S. Mahmoud, S. Kotob, and A. A. Abou-Elseoud, "A Learning Rule-Based Control System", Journal of Information and Decision Technologies, Vol. 18, No. 1, January 1992, pp. 55-66.
[18]. M. S. Mahmoud, A. A. Abou-Elseoud and S. Kotob, "Development of Expert Control Systems: A Pattern Classification and Recognition Approach", Journal of Intelligent and Robotic Systems, Vol. 5, No. 2, April 1992, pp.129-146.
[19]. L. X Wang, "A Supervisory Controller for Fuzzy Control Systems that Guarantees Stability", IEEE Trans. Automatic Control, Vol. 39, No. 9, September 1994, pp. 1845-1847.
[20]. K. M. Passino, and S. Yurkovick, "Fuzzy Control", Addison Wesley, California, 1998.
[21]. Wang, Li-Xin, "A Course In Fuzzy Systems And Control", Prentice-Hall International, Inc. NJ 07458,USA, 1997.
[22]. M. Sugeno, and G.T. Kang, "Structure Identification of Fuzzy Model, Fuzzy Sets and Systems", 28, 1988, pp. 15-33.
[23]. Takagi, and M. Sugeno , "Fuzzy Identification of Systems and its Applications to Modeling and Control", IEEE Trans. On System, Man, and Cybernetics, Vol. 15, 1985, pp. 116-132.
[24]. Seyed Besharat Anjamrooz and Seyed Said Allah Mortazavi, "Simulation and Intelligent Control of Natural Gas Putification", Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345, 2015
[25]. Muhammad M.A.S. Mahmoud, Egyptian, born in Kuwait 1963. Received the B.S. degree in Electrical Engineering from Cairo University and the M.Sc. degree from Kuwait University. First PH.D degree from Transilvania University of Brasov, Romania in IT and Computer. Second PhD Degree in Electrical Power system and Machine, Cairo Univ. Egypt.
[26]. He occupies a position of Senior Electrical Engineer, Skill Pool Expert-Electrical and Co-Chairman PhD Council at Al Hosn Gas Co. His current research interests in Fuzzy and Artificial Neural Network Techniques application include power delivery, protection reliability, control and safety. Dr. Muhammad is of IEEE Member in 1999 and Senior Member (SM) since 2001.

★★★