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Modeling of Intelligent Control System for Liquid Level in Multi-Stage Separator Arrangement in Oil and Natural Gas Industry

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Abstract

The control of liquid level in the oil and natural gas industry is a very important subject since it affects the shutdown of the sale and transport of these sensitive products. In the oil separator, because of the mixing of the accompanied water, oil and accompanied gas, therefore, the level of oil must not be exceed a such rang as well as not to be less than a proper level. For this reason, this work is focused in modeling a Simulink and mathematical model for multi-stage oil separator structure and applies the intelligent schemes in order to control the angles of most inlet and outlet valves at the same time. This technique will improve the behavior of the level response in terms of the rise time, maximum present overshoot, settling time and steady state error. Also, a comparison has been implemented between (fuzzy logic, Nonlinear Autoregressive-Moving Average (NARMA-L2)) against conventional control methods such as PID control. Faster response for most oil separator can be achieved as it appears from the simulation results. Also, multi input variable that affect the system outputs can be treated accurately by a proper rule base adjusting in fuzzy logic or adequate training data in the NARMA-L2. The effective factors of fuzzy logic and NARMA-L2 had been optimized and studied where the simulation results had demonstrated that there are special magnitudes for each new application.

الخلاصة:

ان السيطرة على مستوى الموائع في صناعة النفط والغاز يعتبر من المواضيع المهمة جدا وذلك لتاثيره المباشر عل توقف بيع وتصدير هذه المنتجات الحساسة. في العازلات النفطية وبسبب الخلط بين النفط الخام والماء المصاحب والغاز المصاحب لذلك فان مستوى النفط الخام في العازلة النفطية يجب ان لايتعدى مدى معين وكذلك ان لا يقل عن مستوى محدد له. لقد تركز هذا العمل على بناء موديل رياضي مع نمذجة ل منظومة ذات عازلات نفطية متعددة وتطبيق بعض طرق الذكاء الصناعي مثل طريقة المنطق الضبابيي للسيطرة على زاوية فتحة صمام الدخول والخروج لكل العازلات بوقت واحد. ان هذه التقنية سوف تسيطر على مستوى التدفق للدخول والخروج وبالتالي يمكن السيطرة على مستوى النفط الخام في العازلة. ان هذه الطريقة اثبتت تحسين تصرف الاستجلبة بمقدار كبير من خلال تحسين زمن الوصول والقمة العليبا وزمن التارجح وكذلك خطا المرحلة المستقرة.كذلك تم تنفيذ مقارنة بين طريقة المنطق الضبابي مع احد طرق الشبكات العصبية من جهة والطرق التقليدية من جهة اخرى.لقد اضهرت النتائج مدى تحسن سرعة الاستجابة في كل العازلات مع نسبة خطا قليلة جدا في مرحلة الاستقرار.كذلك فان المتغيرات المتعددة التي ثوثر على المخرجات يمكن السيطرة عليها من خلال اختيار شروط مناسبة لطريقة المنطق الضبابي وكذلك اختيار بيانات تدريب ملائمة للطرق المعتمدة على الشبكات العصبية. لقد نم دراسة كافة العوامل المؤثرة للتقنات الذكية لتحديد افضل القيم التي ئلائم هذا المجال واثبتت النتائج ان هذه القيم تتغير بصورة حساسة جدا مع تغير ضروف المنظومة وخصوصا عند ظهور الديناميكية اللاخطية في الموديل الرياضي.

Key words: Oil level, Oil Separator, Fuzzy logic, NARMA-L2, PID.

1. Introduction

Liquid level is a vital process in most parts of petrol industries .Due to a quit complex mathematical model of oil separators and their containing of three liquids (oil, water and gas), however, many attempt have been implemented for modeling and designing these complicated structures. Also, a proper control schemes have taken a wide effort and time from researchers. Intelligent techniques have starts since some period as well as introducing of computer and automation in order to reach optimum behavior. Many factors need to be controlled in these sensitive and important components such as liquid level, pressure, ability of gas separation, etc... There are many types of oil separator arrangements such as two phase, three phase, etc as shown in Fig.(1).

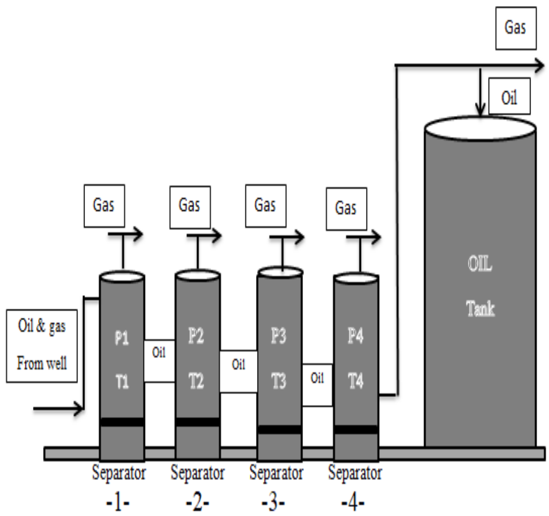

Fig.(1) Oil Separator structure

Minimization of steady –state error has a significant role of the recent models and designs of control systems in different branches especially oil separator. Based on Takagi sugeno method, Miguel et el [1] in 2008 designed a fuzzy controller for controlling oil level in the separator where overall system performance can be improved. Mihaela Raduca et al [2] in 2008 proposed a matlab Simulink model for a fuzzy controller in order to maintain a constant oil level in the production separators. A high precision can be reached since fuzzy method includes linguistic variables. Based on the simulation results proposed by Mihaela et al [3] in 2011, it can be concluded that fuzzy controller is a proper for using in the liquid level control applications. Also, concepts of triangle membership have been produced in this research. Mean square error may be reduced when consideration Artificial neural network as a control tool in coupled tank systems [4] (janani, 2014). In this paper an effective application of ANN named NARMA-L2 has been used where the result show very acceptable performance. A comparison study had been done by Kala et al [5] in 2014.In this work, fuzzy logic controller had appeared a faster response as compared with Zeigler tuned PID controller. Lower overshoot can be obtained although the large variation of the inputs of the system to be controlled. Rajendran and Palani [6] in 2014 proposed a nonlinear case study in order to control the liquid level in a spherical tank using Fuzzy Logic (FL). Based on the some transient response characteristics such as rise time and maximum over shoot, the performance of presented model had given much improved in the reduction of these parameters. As compared with Zeigler-Nicholas tuned PI controller, (FL) scheme model exhibits very small overshoot and can avoid the oscillation problem easily. Thivya and Najaraju [7] in 2015 designed a fuzzy controller for manipulate the water level in the second tank in two series arrangement of cascaded tanks system. After testing the controller at variable pump flow to the first tank, the result show that the proposed method can remove the overshoot and reduce the time domain parameters. A comparison with PID controlling scheme had been done where the fuzzy logic be superior in terms of avoiding the oscillatory of dynamic systems and disturbances treatment. In 2015 John et al [8] proposed a significant study for removal the liquid from steam gas in vertical and horizontal separators. Due to great success of artificial intelligence techniques in the liquid level control, some researches have been done using Fuzzy logic control [9, 10, 11, 12 and 13]. Also, five rules with adequate adjusting of membership can lead to smoothly water level in one tank system using fuzzy logic control technique Mohd et al [14] (in 2017), Where the results had shown a small overshoot and acceptable rise time.

The high complexity of the multi-stage oil separator structure and great nonlinearity of the variation of main input factors had led to use the artificial intelligence in order to introduce the computerized software and hard ware in the petrol and gas industries.

2. Mathematical modeling of multi-stage separators

The arrangement of four series separator can be assembled as shown in Fig.2. The effective relations that manipulate the liquid flow and level can be summarized as it listed below. The derivation takes into account small changes in the variable from the steady state values. In this case of study, laminar flow is considered and eight valves will be controlled automatically by receive a proper signal from the main processor of the control system.

$Q=KH$……………….………..….. (1)

$R_L = \dfrac{\text{change in level defference } (m)}{\text{change in flow rate } (m3/sec)}$…….. (2)

$R_L = \dfrac{dH}{dQ} = \dfrac{H}{Q}$…………………........…..….. (3)

$C_L = \dfrac{\text{change in liquid stored } (m3)}{\text{change in head } (m)}$…...….. (4)

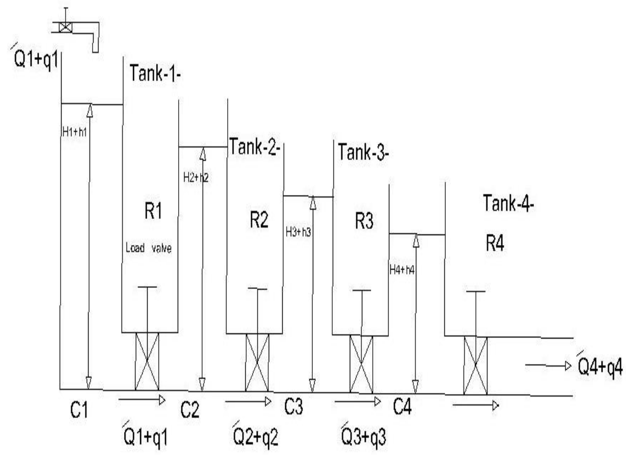

Fig.2 liquid-level system for four tanks.

$C\,dh = (q_i - q_o)dt$………. (5)

$q_o = \dfrac{ho}{R}$………………....….. (6)

$R_1 = \dfrac{h1-h2}{q1}$……………..….. (7)

$C_1 \times \dfrac{dh1}{dt} = q - q_1$………… (8)

$R_2 = \dfrac{h2-h3}{q2}$……………………………………..….. (9)

$C_2 \times \dfrac{dh2}{dt} = q_1 - q_2$……………………………..….. (10)

$R_3 = \dfrac{h3-h4}{q3}$……………………………………..….. (11)

$$C_3 \times \frac{dh3}{dt} = q_2 - q_3 \ldots\ldots (12)$$

$$R_4 = \frac{h4}{q4} \ldots\ldots (13)$$

$$C_4 \times \frac{dh4}{dt} = q_3 - q_4 \ldots\ldots (14)$$

$$C_4\, dh_4 = (q_3 - q_4)\, dt \ldots\ldots (15)$$

$$q_4 = \frac{h4}{R4} \ldots\ldots (16)$$

$$C_4\, dh_4 = (q_3 - \frac{h4}{R4})\, dt \ldots\ldots (17)$$

$$C_4\, dh_4 + \frac{h4}{R4} dt = q_3 dt \quad \ldots\ldots (18)$$

$$R_4\, C_4 \frac{dh4}{dt} + h_4 = R_4\, q_3 \ldots\ldots (19)$$

$$(R_4 C_4 S + 1)\, H_4(S) = R_4 \left(\frac{h3 - h4}{R3}\right) \ldots\ldots (20)$$

$$(R_4 C_4 S + 1)\, H_4(S) = \frac{R4}{R3} (h_2 - R_2\, q_2 - h_4) \ldots\ldots (21)$$

$$(R_4 C_4 S + 1)\, H_4(S) = \frac{R4}{R3} (h_1 - R_1\, q_1 - R_2\, q_2 - h_4) \ldots\ldots (22)$$

$$[(R_4 C_4 S + \frac{R4}{R3} + 1)\, H_4(S) = \frac{R4}{R3} (h_1 - R_1\, q_1 - R_2\, q_2)]\ (\div Q(S)) \ldots\ldots (23)$$

$$\frac{H4}{Q(S)} = \frac{\frac{R4}{R3}\left(\frac{h1}{Qs} - R1\frac{Q1(S)}{QS} - R2\frac{Q2(S)}{QS}\right)}{(R4\, C4\, S + \frac{R4}{R3} + 1)} \ldots\ldots (24)$$

$$\frac{Q1\,(S)}{Q\,(S)} = \frac{1}{RCS+1} \ldots\ldots (25)$$

$$\frac{Q2\,(S)}{Q\,(S)} = \frac{1}{R1C1R2C2\ S2 + (R1C1 + R2\,C2 + R2C1)\,S + 1} \ldots\ldots (26)$$

Sub eq.(26) in eq. (24) :

$$\frac{H4}{Q(S)} = \frac{\frac{R4}{R3}\left(\frac{h1}{Qs} - \frac{R1}{R1C1S+1} - \frac{R2}{R1C1R2C2\ S2 + (R1C1 + R2C2 + R2C1)S + 1}\right)}{(R4\, C4\, S + \frac{R4}{R3} + 1)} \ldots\ldots (27)$$

$$\frac{H4\,(S)}{R4} = Q_4(S) \ldots\ldots (28)$$

$$\frac{Q4\,(S)}{Q(S)} = \frac{\frac{1}{R3}\left(\frac{h1}{Qs} - \frac{R1}{R1C1S+1} - \frac{R2}{R1C1R2C2\ S2 + (R1C1 + R2C2 + R2C1)S + 1}\right)}{(R4\, C4\, S + \frac{R4}{R3} + 1)} \ldots\ldots (29)$$

Where,

Q :Steady state flow rate (m^3/sec)

H_1: Steady state liquid level of tank1(m)

H_2 : Steady state liquid level of tank2(m)

H_3: Steady state liquid level of tank3(m)

H_4: Steady state liquid level of tank4(m)

K :Coefficient (m^2/sec)

For laminar flow:

R_L :Resistance (sec/m^2)

C_L :Capacity(m^2)

3. Artificial Intelligence

The Artificial Intelligence has a great role in many applications since the last three decades. This role has growth because it deals with the convert the human decision to a mathematical solution and then a numerical values, where an important relation between a human intelligence with the machine operation. Intelligence techniques can solve the complex processes that have not mathematical model or relation as well As having high nonlinearity and discontinuity at the time domain. Fuzzy Logic, Neural Network, and Genetic Algorithm are significant types of artificial intelligence where they produce a success performance in different fields of sciences especially the engineering applications (control, identification, prediction, design, etc.)... Therefore this work focuses of the enhancing regarding of liquid level controller of oil and gas separator by means of the uses of intelligent techniques.

3.1Fuzzy logic

Fuzzy logic is one of the effective and important methods of intelligent techniques. It consists of four major parts. The firs is fuzzification part where the linguistic input is converted to numerical values with a range of (0-1) and inputs are divided into number of sub-ranges named memberships which take different types of mathematical equation forms such as triangle, Gaussian, Trapezoidal, etc. The number of memberships depends on the physical behavior of process and the knowledge of the expert which obtained from a long practical working or large number of experiments. However, in this work, three memberships were considered for the inputs and outputs since this number is adequate to cover the main probability variation of these parameters. The second part of fuzzy logic structure is the rule-base which constructed based on the expert information and the hard practical experiments. In this work, the number and type of rules were formulated according to the requirements of oil separator geometry and the input oil pressure as well as the oil and gas outputs. However, several cases had been implemented with 9, 27 and 45 rules.Tabe.1 shows a sample of one case study of the used rules. In the third part of fuzzy, the final numbering values of all rules are implanted in a processing part named inference engine. In this work, minimum value is considered in the calculation of the rule magnitude. Finally, the output crisp value is calculates with different methods (centroid, large maxima, low maxima, etc.) in a part named defuzzification.

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Table. 1 Fuzzy Rule base

AND		INPUT 1											
		S				M				L			
INPUT 2		O1	O2	O3	O4	O1	O2	O3	O4	O1	O2	O3	O4
	S	S	L	S	L	M	M	S	L	L	S	S	L
	M	S	L	M	M	M	M	M	M	L	S	M	M
	L	S	L	L	S	M	M	L	S	L	S	L	S

Where;

s: small ,m: medium, l: large,O1: Output1, O2: Output2, O3: Output3, O4: Output4.

3.2 Nonlinear Autoregressive-Moving Average (NARMA-L2)

NARMA-L2 is an effective application of neural network that can be used to b control systems having much nonlinearities in their dynamics because it can convert this behavior to liner form approximately. This linear dynamic has implemented in the feedback phase. The main parameters that effect the efficiency of this technique should be adjust carefully as they shown in table.2.

Table.2 The main parameters of NARMA-L2.

Parameter	magnitude
Size of hidden layer	13
Sampling interval	0.5 sec
Training samples	400
No.of Delayed plant input	3
No.of Delayed plant output	2
Maximum plant input	70
Maximum plant output	0
Maximum interval value	4 sec
Minimum interval value	0.1
Training epoch	300
Training function	trainlm

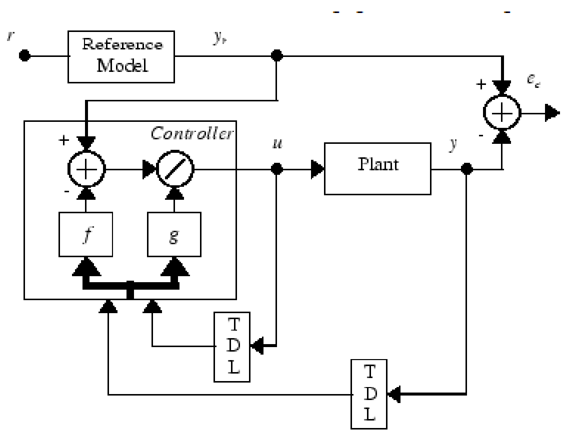

Fig.(3) NARMA-L2 structure.[17].

4. Results and discussion

Some of case studies have been implemented in this paper in order to show the robustness and efficiency of the proposed methods. The variety of the test depends on either the specifications of the intelligent schemes or the number of separators that assembled together. Fig.4 shows a Simulink model for two series separator assembly. In this case, a Fuzzy logic mamdani method has been used with two inputs (levels in seperator1 and 2) and four outputs (two valves opening for each separator). Triangles memberships with (9) rules can produce a proper behavior of levels in both separators mutually as shown in Fig.5.For more confidence, the model is tested with three –series-separator assembly and it appears an acceptable control specification in terms of rise time, maximum overshoot, settling time and steady state error as shown in Fig.6. However, (27) rules lead the system for more stability and safe oil levels in all separators. It can be noticed that, in the three separator case, the simultaneous adjustment of all vales can produce fast control action at the second and third separators with a proper reduction in the overshoot, especially, in the last one. In Fig.7, a Simulink model for four separators arrangement has been implemented and tested with apply of fuzzy logic controller having four inputs and eight outputs. The model had manipulated the system although its complexity because of large number of rules that include the variation of all effective parameters, Fig.8. As compared with PID controller, the proposed scheme appears high efficiency at different cases (Fig.9 and Fig.10). The transient response characteristic has been shown in the tables 3 and 4 where the proposed scheme had appear acceptable ranges of most parameters. Artificial neural network is considered in such effective controller named NARMA-L2, Fig.11. As compared with fuzzy logic NARMA-L2 with a sufficient training data may be as effective controller in this subject of manufactory as it appears clearly in the performance of the first separator in Fig.12.

Table.3 Transient response parameters for one separator case.

Parameters	PID	Fuzzy logic
Overshoot	Present	Not present
Settling time	More	Less
Transient	Present	Not present
Rise time	More	Less

Table.4 Transient response parameters for three separators case.

Parameter	PID	Fuzzy logic
Overshoot	Present	Not present
Settling time	More	Less
Transient	Present	Not present
Rise time	More	More

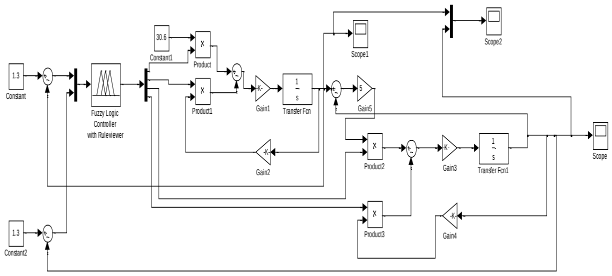

Fig.(4) Two series separators with Fuzzy logic controller Simulink model.

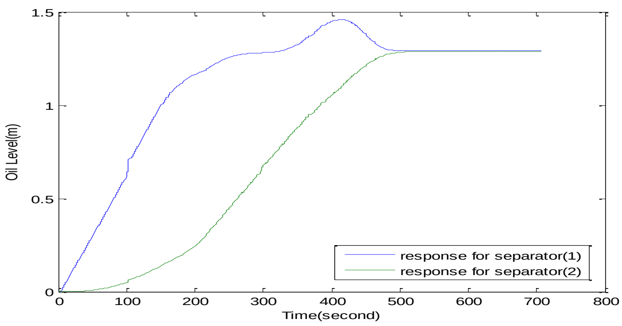

Fig.(5) Responses of oil level for two- separator arrangement using Fuzzy logic controller.

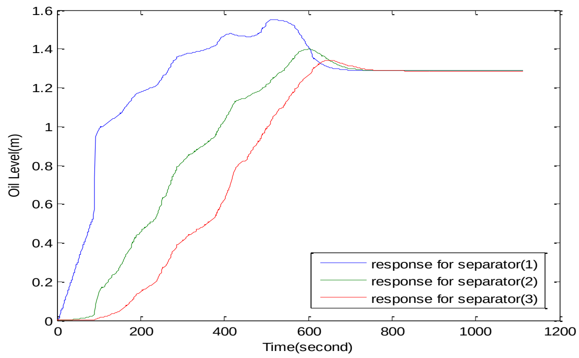

Fig.(6) Responses of oil level in three-separator assembly using Fuzzy logic controller.

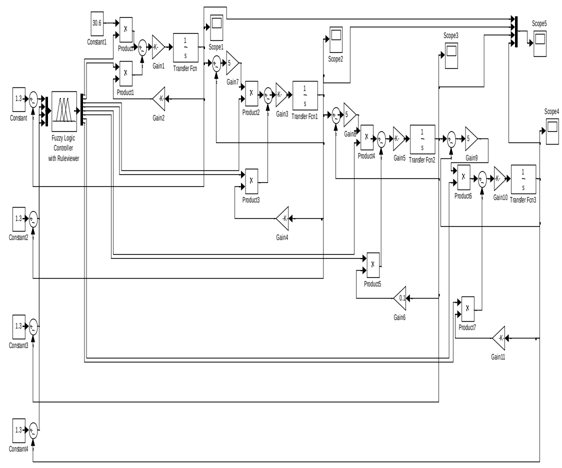

Fig.(7)four series separators with Fuzzy logic controller simulink model

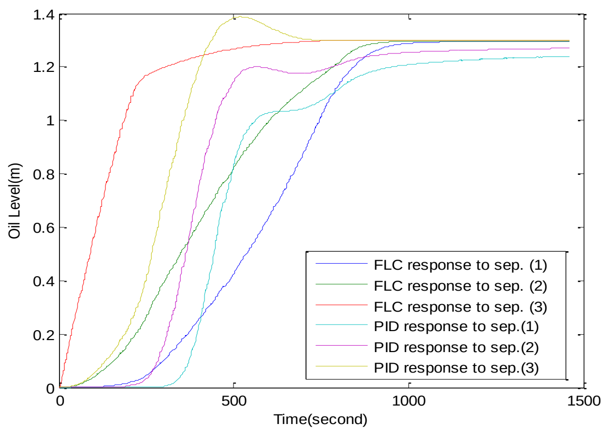

Fig. (10) Comparison of proposed model with PID controller for 3-seperator case.

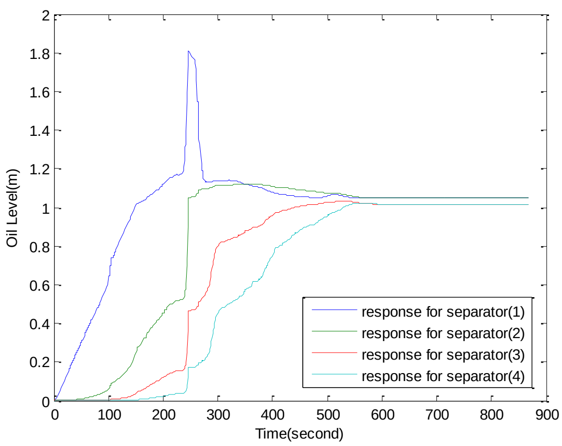

Fig.(8)response of oil level in series four separators.

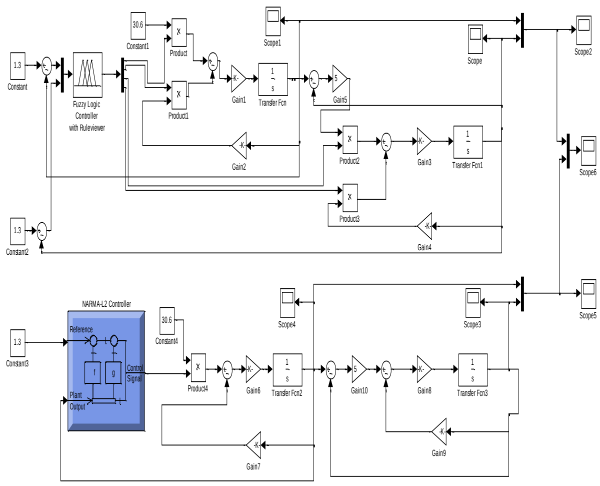

Fig.(11)Two separators with main Fuzzy logic controller as compared with Narma-L2 ..

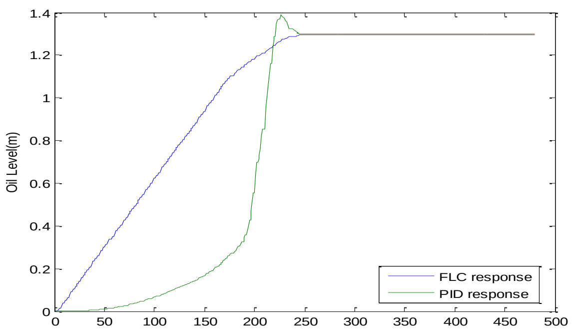

Fig.(9) Comparison of present model with PID control method for one separator.

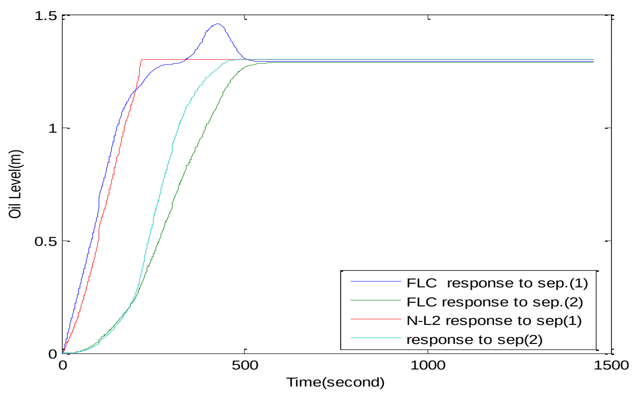

Fig.(12) Comparison of Fuzzy with NARMA-L2.

5. Conclusion

Modeling of multi-phase oil separators have been presented in this paper. The model based on derivation of the mathematical relations that include the effective input parameters corresponding with the main outputs especially liquid levels. With the help of MATLAB, a Simulink model is implemented using artificial intelligence such as Fuzzy logic and NARMA-L2 and tested for several case studies. Also, the effective parameters of NARMA-L2 had been optimized such as size of hidden layer, sampling interval and maximum interval value, where the large number of case studies had led to be concluded that the maximum interval value should be larger than the transient state period with satisfactory amount. At the same manner, the significant factors of fuzzy had been investigated deeply such as the three positions of triangle memberships, number of rules and membership, shapes of membership, defuzzification strategy and number of fuzzy controller in the main Simulink model. The simulation results had clearly appeared the powerful of the proposed strategy in the improving of transient and steady state characteristic of the main responses such rese time, maximum overshoot and steady state error. For more validation of this study, some comparison with conventional methods such ad PID control scheme have been done where the presented model produced high accuracy since it based on the combining of all stage parameters variation in the same time. The steady state error and maximum overshoot had shown acceptable reduction especially in the last separators due to enough time that they have been given to repair their states.

6. Acknowledgment

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7. References

[1]Miguel Angel Ramirez and Canelon Eliezer ColinaMorles, "Fuzzy Model Based control: Application to an oil production seperatr",IEEE, PP.750-757, 2008.

[2]Mihaela Raduca, Eugen Raduca and Aki Uyetani, ""Fuzzy Controller for Adjustment of Oil Level in the Tank", UEM, PP384-391, 2008.

[3] Mihaela Raduca, Eugen Raduca, Cornel Hatiegan, and Dan Ungureanu, "Fuzzy Controller for Adjustment of Liquid Level in the Tank", Article Annals of the University of Craiova Mathematics and Computer Science Series, Vol.4, PP33-43, 2011.

[4]S.Janani and C.Yasotha, "Design and Analysis of Neuro Controller Based on Narma – L2 Model", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering , Vol.3,PP.8425-8430, 2014.

[5]H.Kala, D.Deepakraj, P.Gopalakrishnan and M.KarumbalIyyar, "Performance Evaluation of Fuzzy Logic and PID Controller for Liquid Level Process", International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol. 2, PP.1311-1314, 2014.

[6] S.Rajendran and Dr.S.Palani, " Design and Implementation of Fuzzy Logic Controller for Dynamic System", International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol:14 No:04,2014.

[7] ThivyaPrasad.D, " Artificial Intelligence Based Liquid LevelControl of Coupled Tanks using Fuzzy Logic Controller", International Journal of Latest Trends in Engineering and Technology, Vol. 5, PP. 208-216, 2015.

[8] JohnM.Campbell, "Gas-Liquid Separators Sizing Parameter", Petro Skills, PP.1-16, 2015.

[9] EliezerColinaMorles and Miguel Angel Ramirez Canelon, "Fuzzy Model Based Control: Application to An Oil Production Separator", Eight International Conference on Hybrid Intelligent Systems, PP. 750-757, 2015.

[10]Ashish Singh Thakur, Himmat Singh and SulochanaWadhwani, "Designing of FLC for Controlling of Liquid Level In Couple Tank System", International Journal of Modern Trends in Engineering and Research, Vol.0x, PP. 294-303, 2015.

[11] Ihedioha Ahmed C. and EnehIfeanyichukwu I., " Water Level Monitoring and Control Using Fuzzy Logic System", International Research Journal of Engineering and Technology, Vol.2, PP.1382-1395, 2015.

[12] FaycalChabni, RachidTaleb, AbderrahmenBenbouali and Mohammed Amin Bouthiba ," The Application of Fuzzy Control in Water Tank Level Using Arduino", ", International Journal of Advance Computer Science and Applications, Vol.7,No.4,PP.261-265,2016.

[13] C. Sreepradha, P. Deepa, Rames C. Panda, M. Manamaliand R. Shiva kumar, "Synthesis of Fuzzy Sliding Mode Controller for Liquid Level Control in Spherical Tank", Content Engineering, PP.1-16, 2016.

[14]Mohd Iqbal and Dr.K.A.Khan, "Simulation of Water Level Control in a Tank Using Fuzzy Logic in Matlab",International Journal Of Engineering And Computer Science, Vol.6, PP. 21303-21306, 2017.

[15] Katsuhiko Ogata ,"Modern Control Engineering", Prentice Halstreet, , 2010.

[16] Roland S. Burns, " Advance Control Engineering", Plant a tree, 2001.

[17] The help of Matlab2014b, Mathworks,Inc.,2014.