

Modeling and Performance Analysis of Shell Tube Surface Condenser under Lumped Parameters using Fuzzy Self-tuning PI Controller

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Abstract - Shell tube surface condenser (STSC) is a heat exchanger system that exchange a high pressure steam into low pressure water and it is widely used in applications like textile industries and nuclear power plants. The modelling of the system has been established based on lumped parameters. In this paper, a fuzzy expert system is developed in order to improve the performance of the condenser. A pressure feedback system has been developed to analyze the effect of the condenser output temperature, circulating water flow and heat developed. An experiment has been made for the closed loop system using fuzzy tuned PI, fuzzy logic and PID controllers and a promising results have been obtained successfully.

Keywords - Condenser, Fuzzy self-tuning PI controller, Fuzzy logic, PID

I. INTRODUCTION

The Shell & Tube surface steam condenser condenses the processing vapors emitted from cookers and dryers. The exhaust steam entering the shell from the top flows down over the tubes and gets condensed finally separate by an extraction pump [1].

Here, chilling installation and jade clean are separated via a barrier and condensate is completed by using warmness exchanging finished this barrier support. Cooling element is bimanual via numbers of wet tubes and exhaust steam passes over the outer surface of the tubing. The heat of steam is absorbed via the facility in the cylinder finished the wall of the tube. Again in a few cases, steam is surpassed finished a clothing of clean tubes, cooling wet is sprayed over the steam tubing and condensed steam comes out from the hit of the tubes. Surface steam condensing is slower impact than Jet Steam compression, but the major make of regale water group. In flooring condensers there is no straight communicating between the clean and mechanism nutrient and the condensate can be re-used privileged the vessel : in much condenser flat-bottomed bastardised facility may be old for mechanism entity whereas the cooling facility make to be immaculate in

jet condensers [3]. The majuscule toll and the length requisite is unneeded in steam condensers but it is justified by the saving in strolling soprano and increase in efficiency of communicate carried out by using the use of this condenser. Shell & Tube condenser is a state of steam condenser wherein the steam and chilling thing do now not identify as non-mixing kinds condenser.



Fig. 1. Shell and tube type surface steam condenser [2].

The Figure above suggests the longitudinal form of a convey surface condenser. It consists of a level cylindrical craft made of form iron and engorged of tubes [4]. The cooling facility flows thru those tubes. The ends of the condensers are cut off with the aid of

the perforated kindhearted plates. The tubes are geosynchronous into those punctured identify plates. It is set in much a way that any leakage of facility into the intervening of compression extent is prevented.

The element tubes are bimanual horizontally via the direct compression type. The waste steam from the turbine or engine enters at the top and affected to change descending due to the suction of the air extraction viscus. In this steam condenser, the cooling food enters into vessel thru decrement half of the tubes in one line and returns in word route via the bunk half as shown within the spring of condenser is used in ships as it could feature only a minor abstraction of thing for the tube [6]. It is likewise widely victimized for the land set up where there's a scarcity of genuine uncommon of water.

II. MATHEMATICAL MODELING

The Shell & Tube type surface steam Condenser model is shown in Figure 2 below.

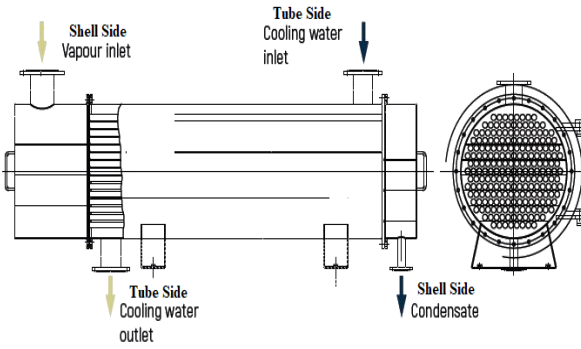


Fig. 2. Model of Shell & Tube type surface steam Condenser [2]

The some following assumption of the condenser. [9]

- Condensing flow is in the shell direction.
- Cooling fluid is considered in tube side.
- The shell pressure loss is negligible.
- The condenser changes the water state from saturated steam to liquid.

A) Mathematical Modeling of the Shell Side Condenser

The shell is the condenser's outermost frame and contains the heat exchanger tubes. The shell is fabricated from carbon metallic plates and is stiffened as had to offer stress for the shell.

B) Steam Zone Mass Equation

$$S_{sh} = \int_0^{t_T} S_T dt + \int_0^{t_{si}} S_{si} dt - \int_0^{t_{vp}} S_{vp} dt - \int_0^{t_c} S_c dt \quad (1)$$

Where: S_{sh} amount of steam in shell side (kg/s), S_T amount of steam in the turbine (kg/s), S_{si} amount of steam enters the condenser (kg/s), S_{vp} steam drawn by vacuum pumping (kg/s), S_c main steam condensate (kg/s).

The amount of steam drawn by the vacuum pumping S_{vp} and the main steam condensate S_c are calculates as:

$$S_{vp} = S_{ao} \left(1 - \frac{p_a m_s}{p_s m_a + p_a m_s} \right) \quad (2)$$

Where: S_{ao} gas mixture quality pumped to the condenser (kg/s) m_a air gas constant kJ/kgK°, p_a air pressure in the condenser (Mpa), m_s steam gas constant kJ/kgK°, p_s steam internal pressure in the condenser (Mpa).

$$S_c = \frac{UA\Delta t_m}{(H_c - H_{cw})} \quad (3)$$

Where : U heat transfer coefficient of the condenser, A heat transfer area of the condenser, H_c enthalpy of steam for condenser pressure, H_{cw} enthalpy of saturated water for condenser pressure, Δt_m heat transfer temperature difference

Vapor Pressure Equation

The vapor pressure equation is calculated as:

$$\frac{dp_s}{dt} = \frac{m_s}{V} \frac{dS_{sh}}{dt} (T_s + 273.5) \quad (4)$$

Where: T_s saturated gas temperature, V volume of gas space in the condenser

Air Zone Mass Equation

The air zone mass equation can be described as:

$$B_a = \int_0^{t_{vp}} B_{vb} dt + \int_0^{t_n} B_n dt + \int_0^{t_g} B_g dt - \int_0^{t_{ex}} B_{ex} dt \quad (5)$$

Where: B_{vb} vacuum break valve air quantity, B_n normal drain condenser air volume, B_g amount of seal leakage air of the condenser, B_{ex} air quality of air extractor

The condenser air pressure equation described as:

$$\frac{dp_a}{dt} = \frac{m_a}{V} \frac{dB_a}{dt} (T_s + 273.5) \quad (6)$$

C) Mathematical Modelling of the Tube Side

Generally, the tubes are product of stainless metal, copper alloys together with brass or bronze, cupronickel, or titanium depending on several choice criteria.

D) Circulating Water Heat Balance Equation

The surface condenser circulating water heat balance equation described as:

$$C_w N_w \frac{dT}{dt} = UA \Delta t_m - F_{cw} N_{cw} (T - T_{cw}) \quad (7)$$

Where : C_w quality of circulating water, N_w quality of heat transfers of circulating water T circulating water outlet temperature, F_{cw} circulating water flow, N_{cw} heat capacity of circulating water, T_{cw} circulating water inlet temperature.

The heat transfer temperature difference can be evaluated as:

$$\Delta t_m = \frac{T - T_{cw}}{\ln\left(\frac{T_s - T_{cw}}{T_s - T}\right)} \quad (8)$$

The product of the heat transfer coefficient U and the heat transfer area A can be approximated as :

$$UA = \frac{1}{\left(\frac{\gamma}{F_{cw}} + (1 - \gamma)\right)} \quad (9)$$

Where: γ is constant

The condensate pressure is described as :

$$p = \frac{RT_{sw}}{V} \int_{t_{sw}}^{t_s} (F_s - F_{sw}) dt \quad (10)$$

Where: R ratio of air in the condenser, T_{sw} saturated water temperature, F_s steam flow, F_{sw} saturated water flow.

The condenser parameters and variables are shown in Table 1 and Table 2 respectively.

Table 1. Parameters of the condenser

Symbol	Parameter	Value
m_a	Air gas constant	0.287 kJ/kg.K°
m_s	Steam gas constant	0.4615 kJ/kg.K°
V	Volume of gas space	25 m ³
C_w	Circulating water quantity	15,400 kg
UA	Heat energy per Kelvin	496 kW/K°
γ	Constant	0.0075

Table 2. Variables of the condenser

Symbol	Variables	Values
F_s	Amount of steam flow	32 kg/s
F_c	Amount of condensate water flow	32 kg/s
T_{cw}	Circulating water inlet temperature	80 °C
T_c	Saturated water temperature	°C

III. PROPOSED CONTROLLER DESIGN

A) Fuzzy Expert system

Fuzzy expert systems were designed to motive via understanding to clear up problems the usage of methods that people use. Professional systems use heuristic expertise as opposed to numbers to control the process of solving the hassle. Professional structures have their expertise encoded and maintained one after the other from the laptop application, which uses that knowledge to resolve the trouble. Expert structures are able to explaining how a particular end turned into reached, and why requested statistics is needed. A FES is an expert system that utilizes fuzzy units and fuzzy logic to conquer some of the issues, which occur when the statistics supplied by way of the consumer are vague or incomplete. The energy of fuzzy set concept comes from the capacity to describe linguistically a particular phenomenon or technique, and then to represent that description with a small quantity of very flexible guidelines [14]. In a fuzzy gadget, the know-how is contained both in its guidelines and in fuzzy units, which hold trendy description of the homes of the phenomenon below consideration. One of the main variations among a FES and another professional gadget is that the primary can infer multiple conclusions. In fact, it gives all feasible solutions whose truth is above a sure threshold, and the person or the utility software can then choose the ideal answer depending at the unique situation. This fact provides flexibility to the machine and makes it greater effective. Fuzzy expert systems use fuzzy statistics, fuzzy regulations, and fuzzy inference, further to the standard ones carried out in the regular professional systems. In building FES, the critical steps are the fuzzification and the construction

of blocks of fuzzy regulations. These steps may be dealt with in two exclusive approaches. The primary is by way of using records obtained thru interviews to the specialists of the problem. The second one is by means of the usage of techniques of device-learning, neural networks and genetic algorithms to analyze club capabilities and fuzzy guidelines. The 2 processes are quite different. The primary does no longer use the past records of the hassle, but it is predicated at the experience of experts who have worked within the area for years. The second is based totally simplest on past statistics and project into the future the identical shape of the past. The primary technique seems premier for our cause, due to the fact no systematic beyond records on business districts are to be had and due to the fact the empirical identification of the industrial districts requires a cautious evaluation in their traits that best experts in this discipline can make.

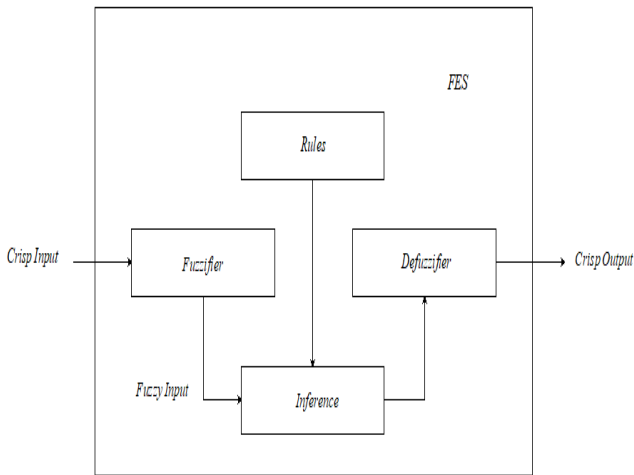


Fig. 3. Fuzzy expert system

B) Fuzzy Self-tuning PI Controller

The self- tuning Fuzzy PI controller (STFPIC) is oriented the signaling order functionary on-line by hirsute rules according to the motion trend of the restrained transmute [12]. The rule-base for tuning the output-scaling effort is defined on error and change of error of the controlled uncertain.

The self-tuning Fuzzy PI controller two parameters k_p and k_i of PI controller are adjusted with the aid of using hairy receiver. The coefficients of the unimaginitive PI controller are not regularly assets adjusted for the nonlinear pass with capricious parameter versions. As an ending, it is needed to

MUSTEFA JIBRIL, MESAY TADESSE, NURYE HASSEN, YONAS ABEBE automatically strain the PI parameters. The structure of the self- tuning Fuzzy PI controller is proven in. In which e is the error between preferred exertion set figure and the yield Δe is the explanation of errors. The PI parameters are tuned by way of using fuzzy receiver, which furnish a nonlinear mapping from e and Δe of blunders to pi parameters [14].

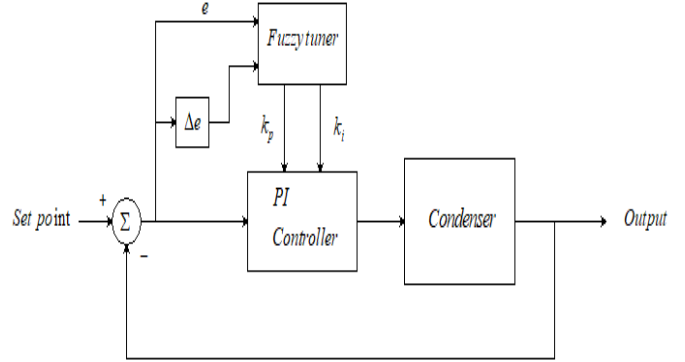


Fig. 4. STSC with self- tuning Fuzzy PI controller.

The membership functions of the inputs k_p and k_i the output F_{cw} are shown in Figures 5, 6 and 7 respectively.

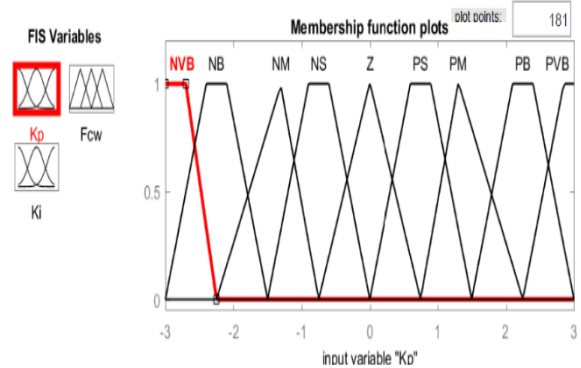


Fig. 5. Membership function of the input k_p .

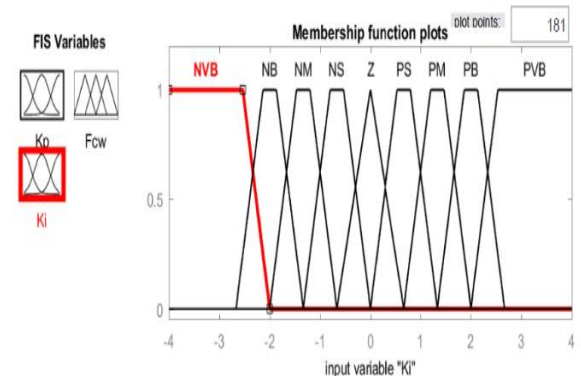


Fig. 6. Membership function of the input k_i .

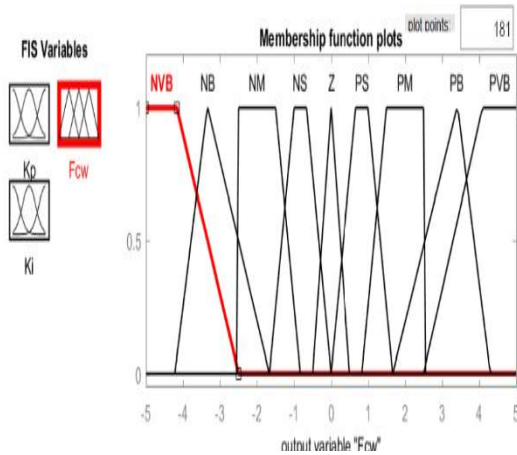


Fig. 7. Membership function of the output F_{cw}

Based on the input membership functions in fuzzification stage and these output membership functions, the number of fuzzy control rules for the Mamdani fuzzy PI controller are 81, which are shown in Table 3.

Table 3. Fuzzy rules table

u	k_i								
	N V B	N B M	N M S	Z	P S	P M	PB	PV	B
N	NS	N	P	P	P	P	P	Z	Z
V		S	V	B	M	M	S		
B			B						
N	N	N	PB	P	P	P	P	Z	Z
B	B	B		M	S	S	S		
N	PV	P	P	P	P	Z	Z	Z	NS
M	B	B	M	S	S				
NS	PB	P	P	P	P	P	Z	NS	NS
		M	M	S	S	S			
Z	P		PS	P	Z	Z	N	NS	N
	M	M		S			S		M
PS	P	P	PS	Z	Z	N	N	N	N
	M	S				S	M	M	B
P	P		Z	N	N	N	N	N	N
M	M	S		S	S	M	B	B	B
PB	Z	Z	Z	N	N	N	N	N	N
				S	S	M	B	B	V
PV	Z	Z	N	N	N	N	N	N	N
B			S	S	M	B	B	V	V
								B	B

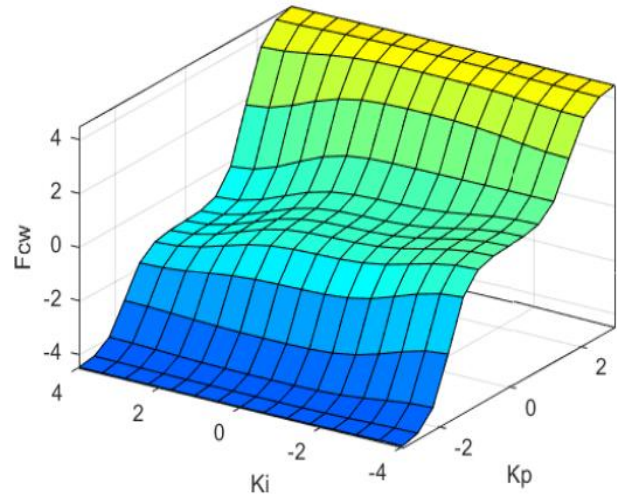


Fig. 8. Input output mapping.

C) Fuzzy Logic Control

Fuzzy logic manipulate has emerged over time and come to be one of the maximum lively areas of research. Fuzzy logic is a shape of probabilistic logic or many-valued good judgment; it deals with approximate reasoning as opposed to constant and specific.

Unlike conventional binary units, where variables take both real or false values, fuzzy logic variables have a fact that ranges in degree among 1 and zero. The truth value may also range between absolutely genuine and completely false. Accordingly, fuzzy logic control has been extended to address the idea of partial reality.

Fuzzy logic is effort of near info or machine getting to live which interprets a hominid's senses. Machine systems can render handiest very or specious values yet a human beingness can grounds the stage of fact or laurels of irreality. Fuzzy models ingeminate the anthropomorphic thinking and are also referred to as natural structures.

D) Fuzzy controller

Fuzzy control (fc) has the gain that it does no longer require a correct mathematical model of the technique.

It uses a set of artificial guidelines in a decision-making desk and calculates an output based totally at the table.

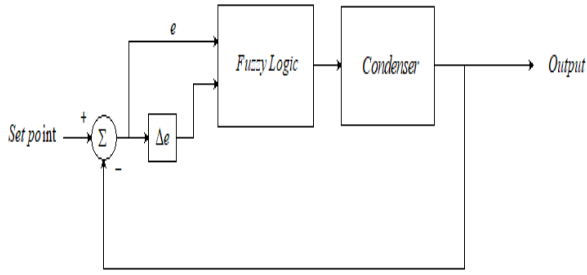


Fig. 9. STSC with Fuzzy logic controller

The membership functions of the inputs e and Δe and the output F_{cw} are shown in Figure 10, Figure 11 and Figure 12 respectively.

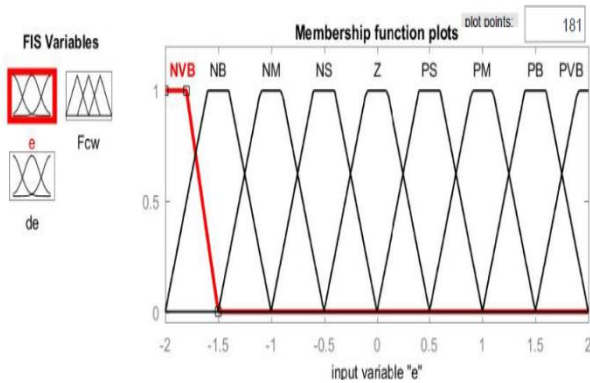


Fig. 10. membership function of the input e

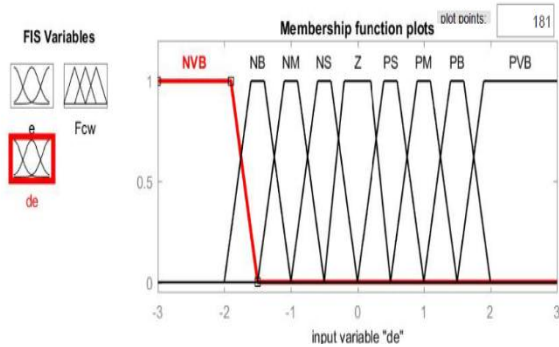


Fig. 11. membership function of the input Δe

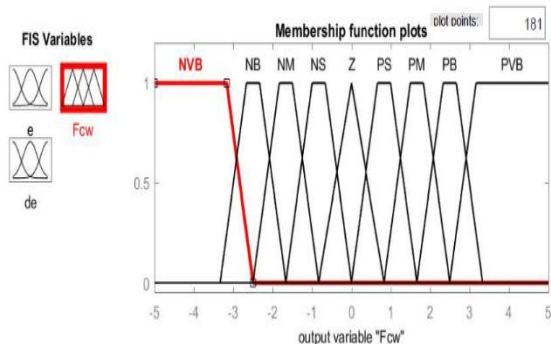


Fig. 12. membership function of the output F_{cw}

A fuzzy control knowledge base must be developed that uses the linguistic description of the input variable [12]. The Fuzzy logic control rules is shown in Table 4.

Table 4. Fuzzy rules table.

u	Δe								
	N	N	N	N	Z	P	P	PB	PV
	VB	B	M	S		S	M		B
N	PV	PV	PV	P	P	P	P	Z	Z
VB	B	B	B	B	M	M	S		
NB	PV	PV	PB	P	P	P	P	Z	Z
	B	B		M	S	S	S		
N	PV	PB	P	P	P	Z	Z	Z	NS
M	B		M	S	S				
NS	PB	P	P	P	P	Z	Z	NS	NS
		M	M	S	S				
Z	P	P	PS	Z	Z	Z	N	NS	N
	M	M					S	S	M
PS	P	PS	PS	Z	N	N	N	N	NB
	M				S	S	M	M	
P	PS	PS	Z	N	N	N	N	NB	NB
M				S	S	M	B		
PB	PS	Z	Z	N	N	N	N	N	N
				S	M	M	B	VB	VB
PV	Z	Z	NS	N	N	N	N	N	N
B				M	M	B	B	VB	VB

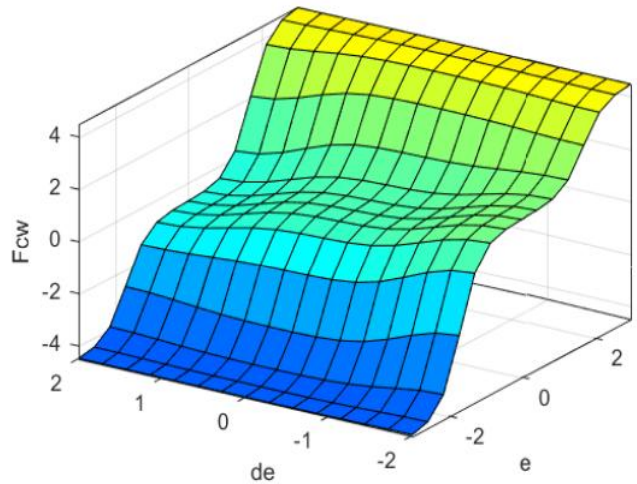


Fig. 13. Input output mapping

IV. RESULT AND DISCUSSION

The effectiveness of the proposed fuzzy self-tuning PI controller is evaluated experimentally with the STSC and is compared with that of fuzzy logic and PID controller which uses the nominal values of the gains obtained by experiment. The proposed

system has been simulated using Mat lab/Simulink Toolbox using pressure set point step change from 90 to 85 Mpa with steam flow of 32 kg/s and circulating water temperature of 80 °C inputs. The Simulink model of the proposed system is shown in Figure 14 below.

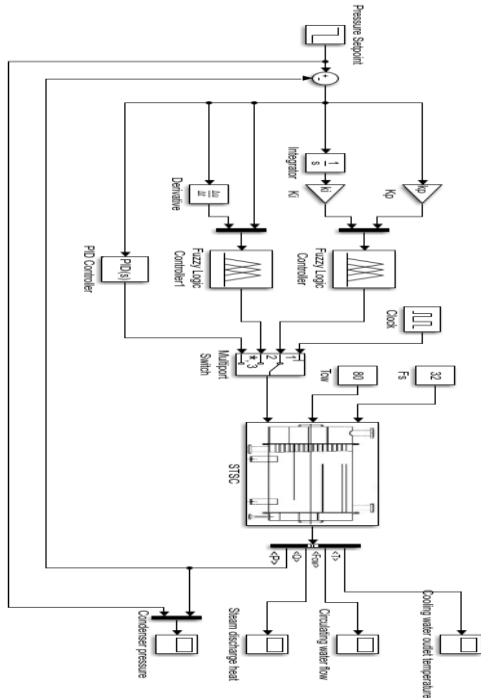


Fig. 14. Simulink model of the proposed system

The parameters of the fuzzy self-tuning PI controller and PID controller are shown in Table 5 below.

Table 5. Gains parameter

Gains	Fuzzy tune PI Controller	PID
k_p	7.3241	7.2402
k_i	0.8732	0.9526
k_d	—	0.9483

Simulation and Experimental Results of the STSC with the proposed controllers

The STSC output simulation results of cooling water outlet temperature, circulating water flow, steam discharge heat, and condenser pressure are shown in Figures 15–18.

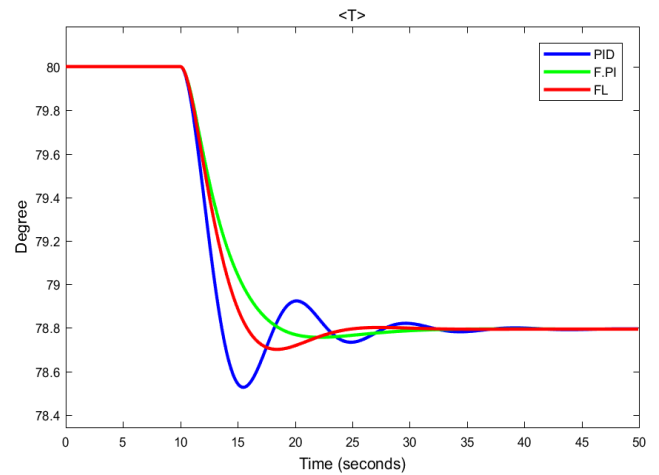


Fig. 15. Simulation result of cooling water outlet temperature

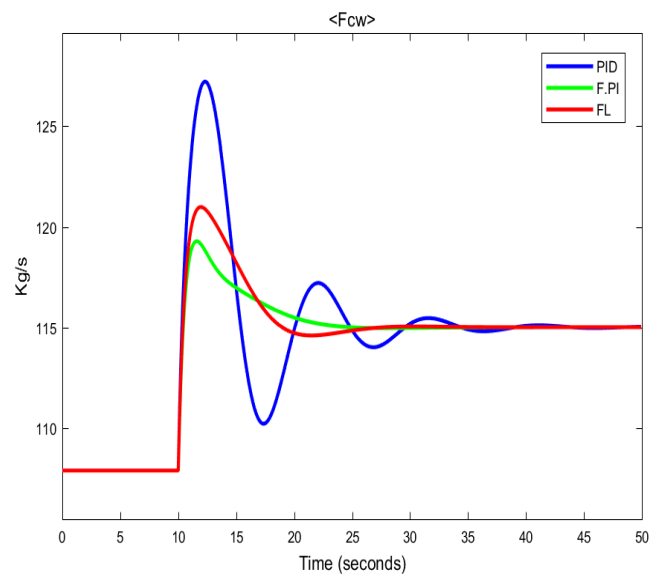


Fig. 16. Simulation result of circulating water flow

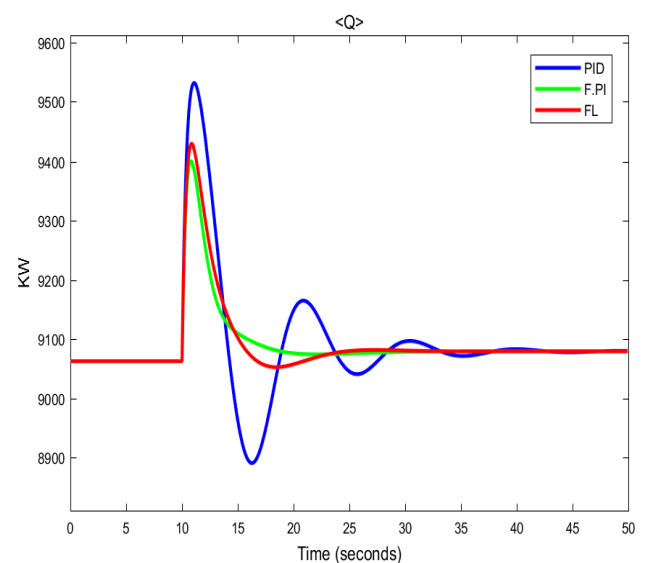


Fig. 17. Simulation result of steam discharge heat

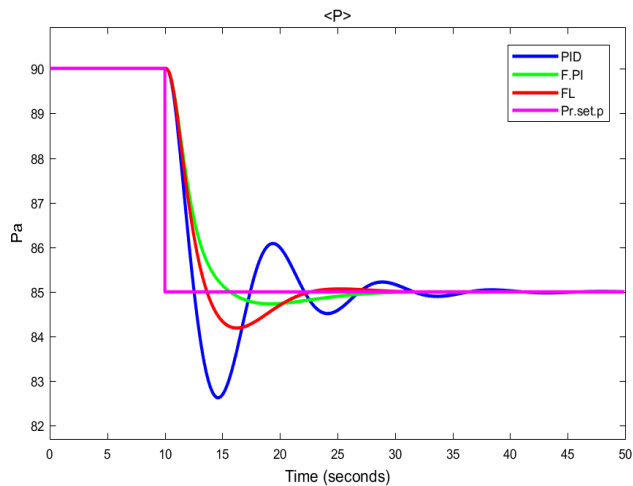


Fig. 18. Simulation result of condenser pressure

As seen from the above simulation results, the fuzzy self-tuning PI controller under the lumped parameters has the best control performance, that is to say, small overshoot and short rise time and settling time. The proposed system with fuzzy logic controller has a good performance, where the overshoot is the larger, the rise time and settling time are longer than the system with fuzzy self-tuning PI controller. The proposed system with PID controller has the worst performance, where the overshoot is the largest, and the rise time and settling time are longest. The fuzzy self-tuning PI controller can effectively improve the system control quality and achieve the desired effect.

V. CONCLUSION

In this paper, modeling and performance analysis of shell tube surface condenser under lumped parameter model is done using fuzzy expert system. A pressure feedback control is used in order to improve the performance of the STSC using a fuzzy self-tuner PI controller. Comparison simulation of the proposed controller with fuzzy logic and PID controllers for the STSC cooling water outlet temperature, circulating water flow, steam heat discharge and condenser pressure shows that the proposed fuzzy self-tuner PI controller has a better performance improvement than the fuzzy and PID controllers.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

- [1] K.Shruthi et al. Increasing the Efficiency of Surface Condenser under Various Load Climatic Conditions by Reducing Sub cooling. *International Research Journal of Engineering and Technology (IRJET)*, Vol. 7, Issue 6, 2020.
- [2] Haarslev Shell & Tube Condenser. Data Sheet Haarslev 2.0, 2019.
- [3] Gaurav Masiwal et al. Performance Analysis of Surface Condenser in 525MW Thermal Power Plant. *International Journal of Engineering and Technology (IJET)*, Vol 9 No 3, doi: 10.21817/ijet/2017/v9i3/1709030186, 2017.
- [4] Priyanka Padgil et al. Heat Transfer Enhancement in Shell and Tube Condenser. *International Journal of Current Engineering and Technology*, Special Issue-7, 2017.
- [5] R. Llopis et al. A Dynamic Model of a Shell-and-Tube Condenser Operating in a Vapour Compression Refrigeration Plant. *International Journal of Thermal Sciences*, DOI: 10.1016/j.ijthermalsci.2007.06.021, 2017.
- [6] Gaurav Shukla. Mathematical Modeling and Simulation of Multicomponent Condenser for the condensation of Hydrocarbon vapour mixture using MATLAB. *International Journal of Scientific Development and Research (IJS DR)*, Volume 2, Issue 5, 2017.
- [7] Masoud Abedinifar. Hybrid Intelligent Controlling Action in Cold Fluid Outflow Temperature Of Shell And Tube Heat Exchangers. *Int. J. Adv. Res.* 4(11), 784-790, 2016.
- [8] Kanakapudi Pradeepkumar et al. Experimental Investigation on Improving the Performance of Surface Condenser in a 120 MW KTPS Thermal Power Plant. *International Journal of Advanced Scientific Technologies in Engineering and Management Sciences*, Volume.2, Issue.12, 2016.
- [9] Pradeep Wagh et al. Optimization of a Shell and Tube Condenser using Numerical Method. *Int. Journal of Engineering Research and Applications*, Vol. 5, Issue 7, pp.09-15, 2015.
- [10] R. Trentini et al. Modeling, Parameter Estimation and State-Space Control of a Steam Turbine. 23rd ABCM International Congress of Mechanical Engineering (COBEM 2015) December 6-11, Rio de Janeiro, RJ, Brazil, 2015.
- [11] Haile Araya Nigusse et al. Performance Analysis of a Shell Tube Condenser for a Model Organic Rankine Cycle for Use in Geothermal Power Plant. *Int. Journal of Engineering Research and Applications*, Vol. 4, Issue 8, pp.141-147, 2014.
- [12] Kwanchai Sinthipsomboon et al. A Hybrid of Fuzzy and Fuzzy Self-Tuning PID Controller for Servo Electro-Hydraulic System. *Recent Advances in Theory and Applications*, DOI: 10.5772/48614, 2012.
- [13] Mehta Vijay et al. Optimization in Area by Changing Number of Passage in Shell of Surface Condenser. *International Journal of Engineering Research & Technology (IJERT)*, Vol. 1 Issue 5, 2012.
- [14] K.A.Gopala Rao et al. Fuzzy Pi And Integrating Type Fuzzy Pid Controllers Of Linear, Nonlinear And Time -Delay Systems. *International Journal of Computer Applications*, Vol. 1, No. 6, 2010.