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Design and Development of Fuzzy Logic Controller for Consistency Control of Pulp

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Abstract: In this Paper fuzzy logic controller has been designed for consistency of paper as a SISO system. Fuzzy knowledge base controller is used to control the pulp consistency. Here we used fuzzy logic controller to adjust the valve, because fuzzy logic controller is based on operator's experience and data provide by the paper mill. Fuzzy logic control system is one of the most techniques in which FLC does not require the knowledge of the mathematical modeling of the system instead it requires the knowledge of human expert. Fuzzy logic controller based on the specific requirement of the system and output of the system is evaluated by simulation for consistency.

Keywords: Pulp consistency, Fuzzy logic controller, headbox.

I- Introduction

First step in the paper making process is the uniformly distributed of pulp stock material from the paper machine headbox onto the wire. Headbox is the most important subsystem of the paper machine. The headbox has many attributes which are highly significant for all paper makers. Uniformity of flow, absence of streaks and large eddies, headbox stability and ease of operation are features which is required for all paper grades. In the paper making process the paper sheet contains by the fiber, water and filler. Paper sheet is depending upon the some parameters like consistency of the pulp, dilution water, and thick stock. For high quality rolls and reels of paper, basis weight as well as its moisture content is necessary to control [2]. The basis weight of the paper sheet from a paper making machine is measured by gamma gauge. The most common interaction between basis weight and moisture is considered, but headbox is very complex system so it is difficult to control with classical controller & does not give satisfactory result in the presence of disturbance. Hence fuzzy logic controller is used to enhance the performance of the headbox. Fuzzy logic is very simple because it is only based on the human expert. In fuzzy logic controller we can changed easily in input variables and output variables. Fuzzy logic control system can interpreted as a real time expert system combining if-then rules. Firstly we identify inputs and outputs variables in fuzzy controller [3].

II- System Description

The paper machine head box is a subsystem of paper making process. The headbox consists of a pond section, dispersing devices and slice open equivalent to the width of wet end paper machine at its bottom. It can be either open to atmosphere or closed with arrangement for applying air pressure at the top of the stock. Headbox is used for high speed machine, does not contain moving part or rotary devices and it is controlled by the pressure of fan pump. The modern headbox has many attributes which are highly significant for all papermakers. Uniformity of flow, absence of streaks and large eddies, headbox stability and ease of operation are features which are requirement for all paper grades. In paper making process, the most common interaction is between basis weight control and moisture control. If we will increase the stock flow than the amount of water to be evaporated increase and also moisture contain will increase with the help of basis weight controller increases. Due to all parameters, the headbox model is difficult to design in some domain. The idea of fuzzy control is to build a model of a human control expert who is capable the plant without thinking in a mathematical model. On the present investigation, fuzzy logic controller has been designed for consistency control to enhance the performance of the system. The consistency of paper depends on the amount of stock flow and dilution water.

III- Process Dynamics

For high quality rolls and reels of paper, basis weight as well as its moisture content is necessary to control. Basis weight of paper depends on some factor like consistency (the dilution water added is well mixed with the stock before reaching the consistency sensor). It is possible to control consistency on the basis of either a sample taken from a main stream or by making the appropriate measurement directly in the main channel of flow. Thus the process as a whole has one controlled output i.e. basis weight and two manipulated inputs i.e. dilution valve and thick stock valve. Carrying out bump test on the approach flow on the approach flow system flow loop, Nancy (1) developed dynamic equation in form of first order with dead time. In one of such equation, the dead time was reported of the order of 6.84 which is due to transmitter location relative to the dilution point. The time constant of 3.84s is due the sensor measurement dynamics.

$$\mathbf{G_p(s) = -2.035e^{-6.84s}/(1+3.8s)}$$

The mass balance for a steady state system with respect to consistency in headbox consists of two inlet flows with two inlet consistency. The symbols are given in nomenclature.

$$m_i\, c_{yi} + m_d\, c_{yd} = m_o\, c_{yo} \qquad [1.1]$$

Overall mass balance on the same system
At steady state , t=0, $m_o=m_{os}$, $m_i=m_{is}$; $m_d=m_{ds}$, $m_o=m_i+m_d$ [1.2]
At unsteady state, Input=output + accumulation for fiber balance using consistency of each flow
$m_i\, c_{yi} + m_d\, c_{yd} = m_o\, c_{yo} + d(V\rho\, c_{yo})/dt$ [1.3]
Also, overall mass balance is written as,
$m_i + m_d = m_o + d(V\rho)/dt$ [1.4]
For constant density and constant volume thin stock system at steady state,
$d(V\rho)/dt=0$ and therefore $m_i + m_d = m_o$
Eqn.[1.3] can be written as
$V\rho d(c_{yo})/dt = m_i\, c_{yi} + m_d\, c_{yd} - m_o\, c_{yo}$ or $d(c_{yo})/dt = (1/V)\{(m_{i\,/\,\rho})\, c_{yi} + (m_{d\,/\,\rho})\, c_{yd} - (m_{o\,/\,\rho})\, c_{yo}\}$
Or $d(c_{yo})/dt = (1/V)\{q_i\, c_{yi} + q_d\, c_{yd} - q_o\, c_{yo}\}$ [1.5]

Expressing in terms of deviation variables, eqn.[1.5] can be written as given below
At t=0,

$c_{yi} \rightarrow c_{yis}$
$c_{yd} \rightarrow c_{yds}$
$c_{yo} \rightarrow c_{yos}$

$d(c_{yo} - c_{yos})/dt = (1/V)\{ q_i(c_{yi} - c_{yis}) + q_d(c_{yd} - c_{yds}) + q_o(c_{yo} - c_{yos})\}$
$d(C_{yo})/dt = (1/V)\{Q_i C_{yi} + Q_d C_{yd} - Q_o C_{yo}\}$ [1.6]

where $C_{yo} = c_{yo} - c_{yos}$; $C_{yi} = c_{yi} - c_{yis}$; $C_{yd} = c_{yd} - c_{yds} = 0$

Eqn.[1.5] can be dealt with for two cases:

Case -a: Constant dilution water density, volume, flow and consistency at a variable inlet stock flow consistency which is clearly a SISO system.

Case –b: Variable inlet stock flow at constant consistency and constant dilution water flow consistency and variable input consistency which indicates an interactive process containing two variables which is a MIMO system.

Case-a: The balance eqn. [1.6] reduces to

$$d(C_{yo})/dt = (1/V)\{ Q_i\, C_{yi} - Q_o C_{yo}\} \qquad [1.7]$$

If $Q_i = Q_o$, flow remains constant
$d(C_{yo})/dt = (Q/V)\{C_{yi} - C_{yo}\}$ or $C_{yi} = C_{yo} + (V/Q)\, dC_{yo}/dt = C_{yo} + \zeta\, dC_{yo}/dt$
$C_{yi}(s) = C_{yo}(s) + \zeta\, sC_{yo}(s) = C_{yo}(s)[1 + \zeta\, s]$
$C_{yo}(s)/\, C_{yi}(s) = [1/(1 + \zeta\, s)]$ [1.8]

Effective process transfer function for the consistency control
$G_p = K_p/(\zeta\, s + 1)$ [1.9]

Case-b:

The balance equation can be written as

$m_i\, c_{yi} + m_d c_{yd} = m_o\, c_{yo} + d(V\, \rho\, c_{yo})/dt$ [1.10]
$\rho V d\,(c_{yo})/dt = m_i\, c_{yi} + m_d c_{yd} - m_o\, c_{yo}$
$d(c_{yo})/dt = (1/V)\{q_i\, c_{yi} + q_d c_{yd}\}$ [1.11]
In terms of deviation variables,
$d(c_{yo})/dt = (1/V)\{Q_i\, Cy_i + Q_d C_{yd} - Q_o C_{yo}\}$ [1.12]
Where,
$d(c_{yo}V)/dt = Vd(c_{yo})/dt + c_{yo}dV/dt$
Substituting the value of $d(c_{yo}V)/dt$ in eqn.[5.10], eqn.[5.10] can be written as
or $m_i\, c_{yi} + m_d c_{yd} = m_o\, c_{yo} + \rho\, V\, dc_{yo} / dt + \rho\, c_{yo}\, dV/dt$ [1.13]
or $c_{yi}\, q_i + c_{yd}\, q_d - c_{yo}\, q_o = V\, dc_{yo}/dt + c_{yo}\, dV/dt$

Substituting dV/dt from the overall mass balance and canceling terms, one can get:

$dc_{yo}/dt = Q_i/V\, (c_{yi} - c_{yo}) + Q_d/V\, (c_{yd} - c_{yo})$ [1.14]
or $c_{yo}(s + Q_i/v + Q_d/v) = Q_i/v(c_{yi}) + Q_d/v(c_{yd})$
if $c_{yd}=0$; then eqn.[1.14] can be written as
$c_{yo}(s + Q_i/v + Q_d/v) = Q_i/v(c_{yi})$
or $c_{yo}/\, c_{yi} = [Q_i/(sv + Q_i + Q_d)]$
or $c_{yo}/\, c_{yi} = [Q_i/(\zeta_1\, s+1)]$ [1.15]
if $c_{yi}=0$, then eqn.[1.14] can be written as
$c_{yo}(s + Q_i/v + Q_d/v) = Q_d/v(c_{yd})$
$c_{yo}/\, c_{yd} = [Q_d/(sv + Q_i + Q_d)]$
$c_{yo}/c_{yd} = [Q_d/(\zeta_2 s+1)]$

IV- Fuzzy Logic Controller

Fuzzy logic controller scheme shown in Fig.1. The fuzzy logic controller is basically divided into three parts.1-fuzzyfication 2-fuzzy Inference Engine 3-defuzziffication

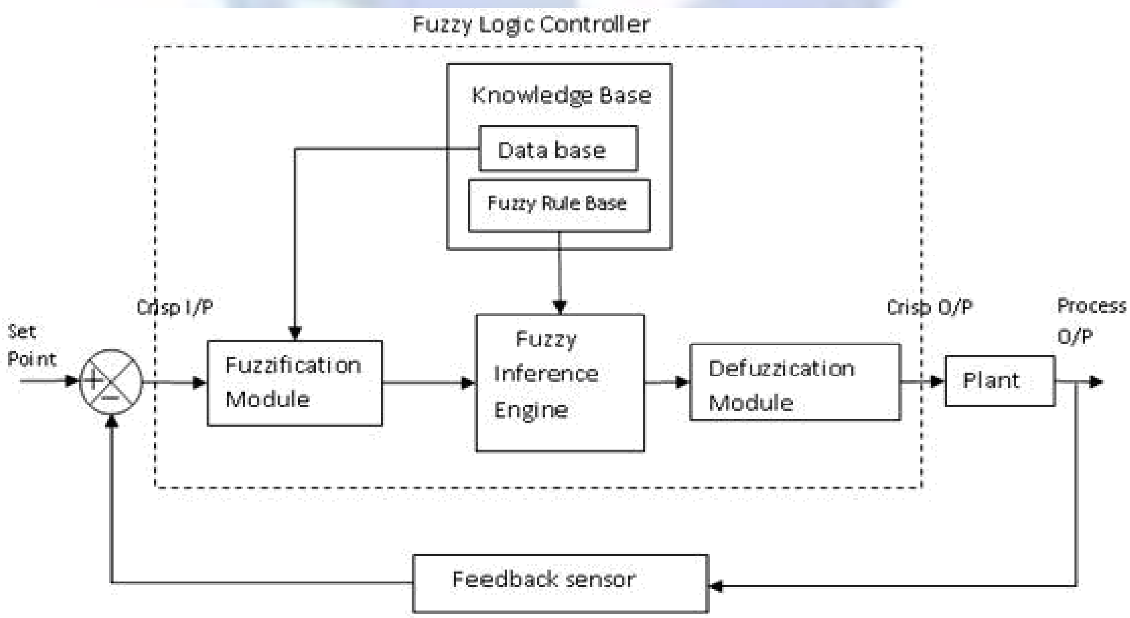

Fig.1. Fuzzy logic Controller

V- Fuzzy Logic Controller: Inputs/outputs

Fuzzy Knowledge baesd controller is used to design the process. Firstly we have identified input and outputs varibles. Error in the consistency (error) and the rate of change of error in the consistency (error dot) are taken as inputs and output is the dilution valve or thik stock valve, Defining the inputs and outputs variables & than define the linguistic variables and draw the membership funtion. In a fuzzy logic controller we have to make all rules according to input, output and linguistic variables.

Fig.2 shows that the mamdani type of fuzzy controller is used. Generally we uesd mamdani type fuzzy logic controller because it has membership function or distribution.

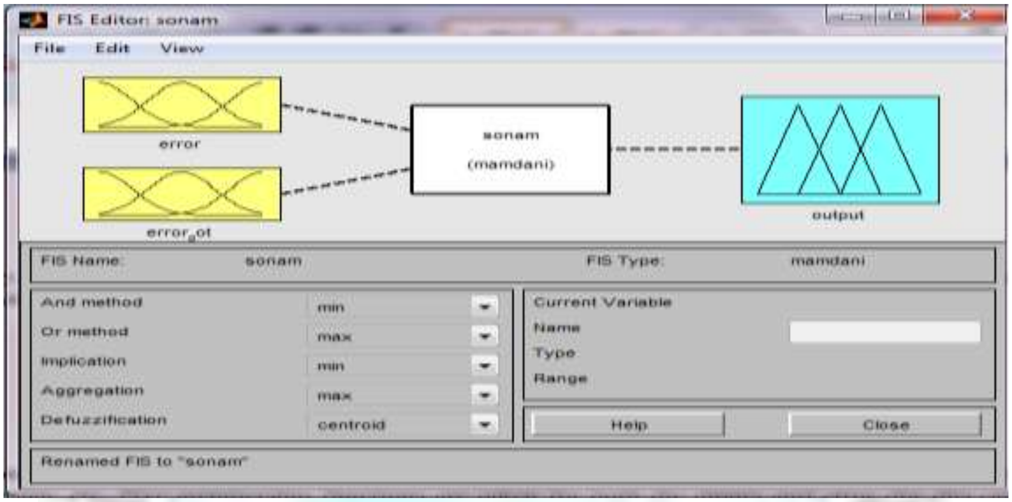

Fig. 2: Fuzzy logic system structure

There are different types of membership functions like triangular membership function, trapezoidal, Gaussian, etc. We choose five membership functions for both the inputs error and error dot & this is shown in the MATLAB window. Here, different-different values were tested until that ones produced the best result. The membership functions for both inputs are shown in Fig.3. & Fig.4.

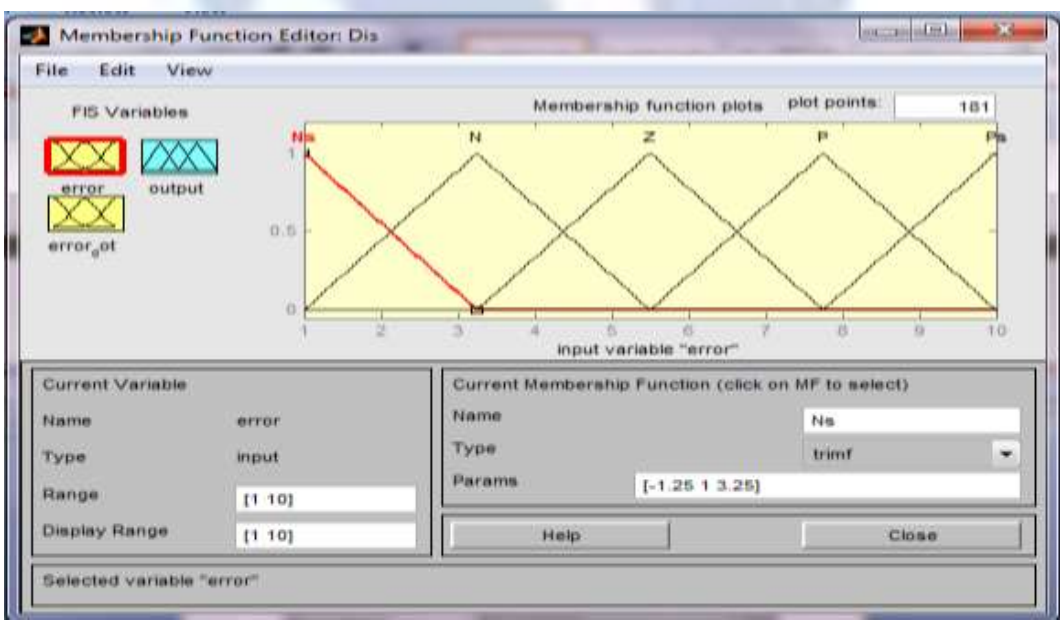

Fig. 3: Membership Function of input variable (error)

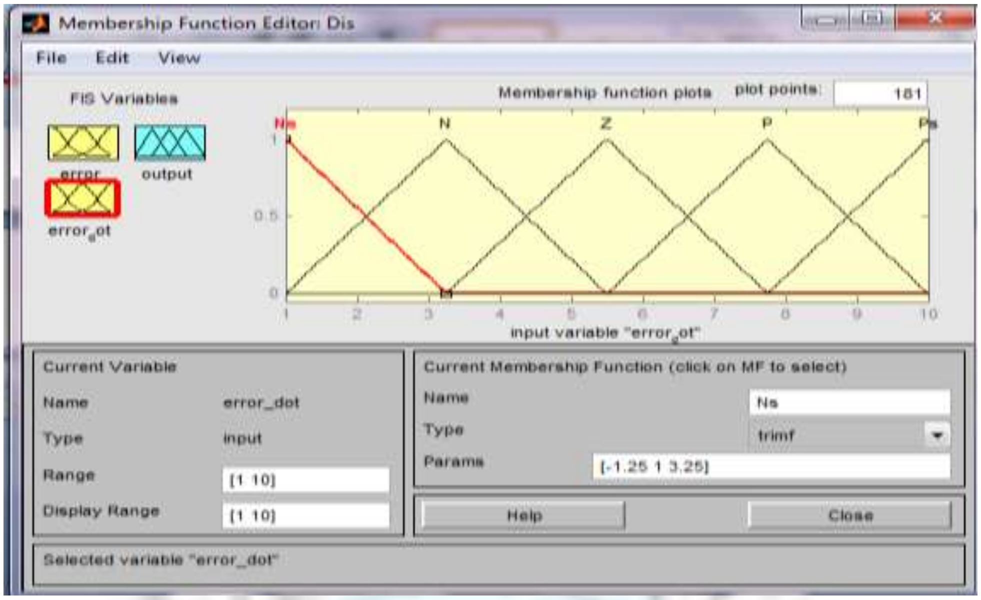

Fig. 4: Membership function of input variable (error dot)

Fig.5.shows the output of fuzzy logic controller i.e. the dilution water valve opening and closed or thick stock valve opening and closed in the MATLAB window.

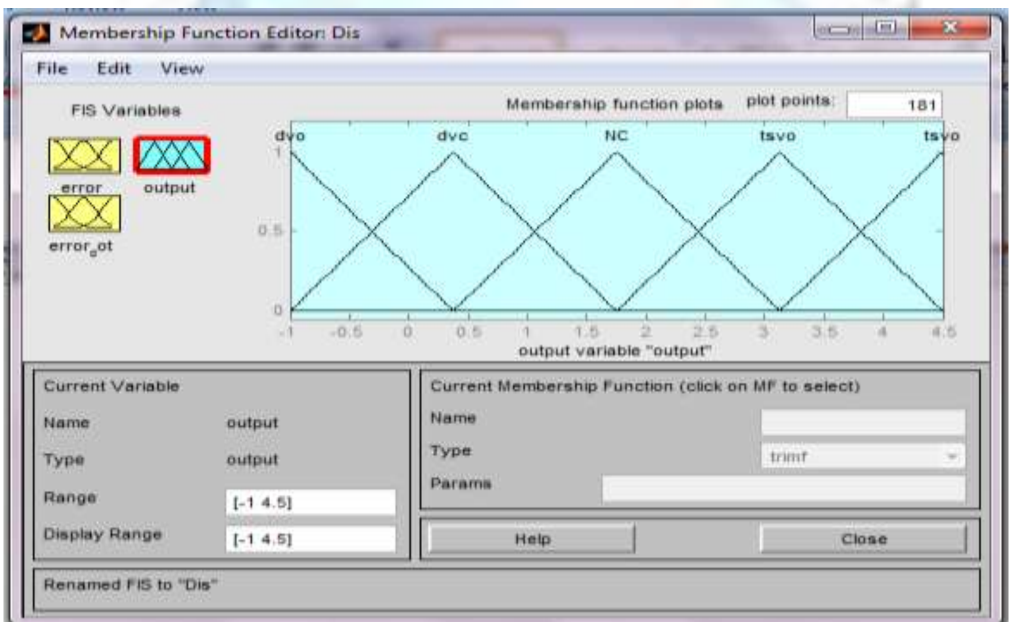

Fig. 5: Membership function of output Variable

VI- Linguistic variable

Each linguistic variable may be assigned one or more linguistic values, which are in turn connected to a numeric value through the mechanism of membership function. The input variables and output variables divided in several classes. The five classes for both input variables and output variables can be used. There are negative small (NS), negative (N), zero (Z), positive (P), positive small (PS) and dilution valve open (DVO), dilution valve closed (DVC), no change (NC), thick stock valve open (TSVO), thick stock valve closed (TSVC). In this case triangular membership function has been used.

Triangular Membership Function: The triangular curve is a function of a vector, a, and depends on the three scalar parameters x, y, and z as given by

$$\mathbf{f(a;x,y,z)} = \begin{cases} \mathbf{0}, & \mathbf{a \le x} \\ \dfrac{\mathbf{a - x}}{\mathbf{y - x}}, & \mathbf{x \le a \le y} \\ \dfrac{\mathbf{z - a}}{\mathbf{z - y}}, & \mathbf{y \le a \le z} \\ \mathbf{0}, & \mathbf{z \le a} \end{cases}$$

The parameter x and z locate the "feet'' of the triangle and the parameter y locates the peak.

VII- Fuzzy rules base

To make the rules in FLC, we should have the full knowledge of the plant. It is based on the knowledge of human expert that how the output is varied with variation of input. Here 25 no. of rules are formed. After designing the rule base, the shape of membership function is decided. Here is used the triangular shape which is decided according to requirement.

e de	**Ns**	**N**	**Z**	**P**	**PS**
NS	DOV	DVO	DVO	TSVO	NC
N	DOV	DVO	DVC	NC	TSVO
Z	DVC	DVC	NC	TSVO	TSVO
P	DVC	NC	TSVO	TSVO	TSVC
PS	NC	TSVO	TSVO	TSVC	TSVC

VIII- Defuzzification

There are the two main techniques of defuzzification in case of fuzzy controller, i.e mean of maxima and center of gravity.

Mean of maxima:- Mean of maxima techniques applies to the fuzzy output O(p) by taking the mean of P values. $P_{1,}$ $P_{2......}P_n$ are the maximizing points of O(P) [4].

$$\mathbf{Mean\ of\ maxima\ [O(P)]} = \frac{\mathbf{P1 + P2 + \cdots + Pn}}{\mathbf{n}}$$

Center of gravity:- Center of gravity techniques is most commonly used because this techniques is very accurate.

$$\mathbf{output} = \frac{\sum_{i=0}^{n} \mathbf{(center \times strenght)}}{\sum_{i=0}^{n} \mathbf{(strength)}}$$

N is the member of output member

IX- Model Development

MATLAB software is used for modeling and simulation. The simulink model shown in Fig.6 is developed which has a fuzzy controller with a rule viewer, a process with transport time delay, a vector concatenate, and scope window.

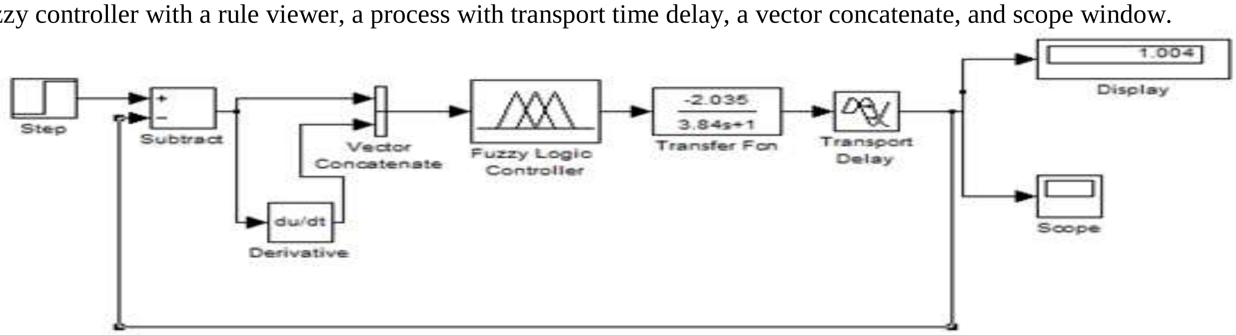

Fig.6.The simulink model showing various blocks of the feedback loop with a process and a fuzzy logic controller

The Fuzzy logic controller with rule viewer shown in Fig.7. This type of block called the fuzzy controller with rule viewer block. The rule viewer opens when the simulink simulation starts.

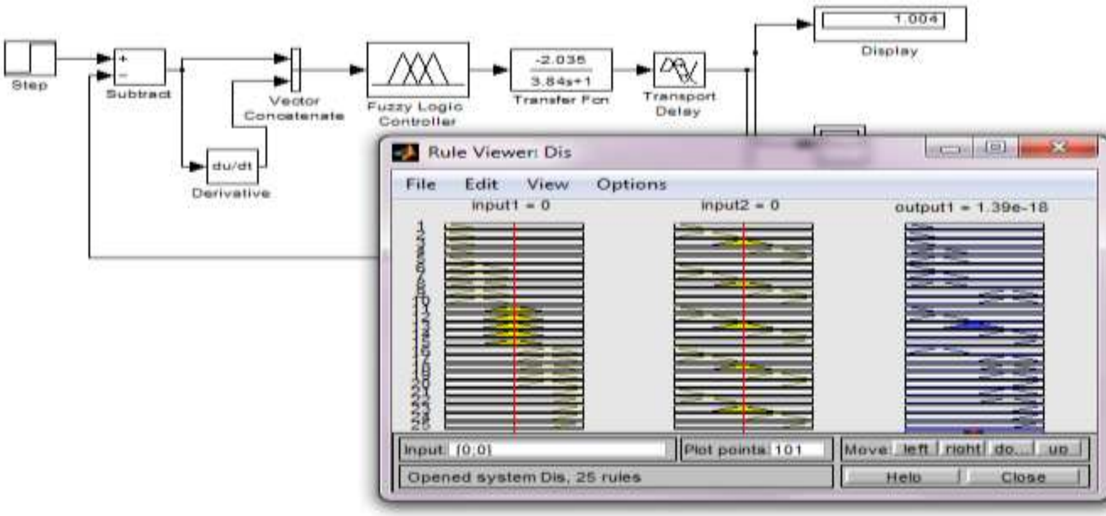

Fig.7. Simulink window with rule viewer

The response of SISO system which is designed for controlling the basis weight of the paper using fuzzy logic controller is shown in Fig.8. in which time is taken on X-axis and basis weight of the paper as output response is taken on Y-axis. The analysis is done by calculating the rise time, settling time, peak time which are shown in table 1.

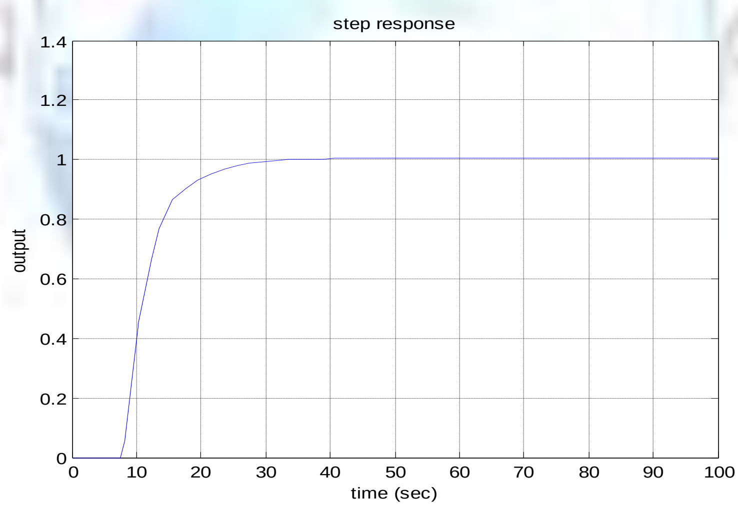

Fig. 8. Performance of the model

Table:-1 Performance Parameter of FLC

Parameters	**fuzzy**
Rise time	**7.8445** sec
Settling time	**27.2676 sec**
Peak	**1.0038**
Overshoot	**0.0238 %**

Conclusion and Future Scope

The system which is to be simulated, working properly and response of the system are coming out to be almost stable. A large number of highly successful fuzzy control application are execute in process industry. Fuzzy logic control technique is widely used in the system where nonlinearities are present and order of the system is very highly so mathematical modeling of the system is very complicated. This technique can be used in automation of different section of various process industries such as refinery, paper industry, tyre industry, polyplex industry, cement industry etc. Fuzzy logic control can also be used in automation of electronics application such as washing machine, electronic toaster, air conditioner etc.

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