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Prediction of Faults using Hydrocarbon Gases Data of Mineral Oil Immersed Power Transformers using Computer Intelligence

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Abstract

This work proposes the separation of Faults diagnosed from Hydrocarbon Gas Data Collected from Dissolved Gas Analysis of Power Transformers over a period of a Decade in the area of Tirunelveli District in South India. The condition of Power Transformers is diagnosed using Fuzzy Set Theory. (FST) Simulations are compared with conventional methods. The computational Efficiency ,Reliability and Success are evaluated and compared. FST is found to be more reliable ,efficient and its success rate is also high.

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Key words: Hydrocarbon Gases, DGA, MATLAB Simulink, Roger Fuzzy System

Introduction

Dissolved Gas Analysis has been used extensively for more than 40 years. It is a very efficient tool for the early diagnosis of fault assurance and increases the opportunity for precautionary measure. Most of the Electrical facilities in South India were commissioned in the late 1950s .FIG.1.shows the Distribution Growth since 1957 in TamilNadu[**website of TNEB**].In certain Substations and Distribution areas, the Electrical Switch Gear and Systems are more than 50 years of age. Depending upon the usage of the Equipment and Environmental conditions, they may be at the nearer end of their useful lives. Transformers are some of the most efficient Electrical Machines with some large units able to transfer 99.75% of their input power to their output. In larger Transformers part of the problem is removal of heat. Mineral oils are used for insulation and the windings immersed in this oil transfer heat to the oil thereby getting cooled. The oils are the mixture of many different Hydrocarbon Molecules which decompose under high Thermal and Electrical Stress within the transformer during the period of service .The critical changes are the breaking of Carbon-Hydrogen and Carbon-Carbon bonds as a result of which different gases are formed due to the presence of individual Hydrocarbon and the distribution of Energy and the Temperature in the neighbourhood of the fault. The causes of fault gases can be divided into three categories **[Joseph B.DiGiorgio]**.

a)Corona or Partial Discharge
b)Pyrolysis or Thermal Heating
c)Arcing

These three categories differ mainly in the intensity of energy that is dissipated per unit time per unit volume by the fault. The most severe intensity of energy dissipation occurs at Arcing, less with Heating and least with Corona.
The fault gases that can be found in a unit are Hydrocarbons like HydrogenH_2, Methane CH_4, Ethane C_2H_6, Ethylene C_2H_4, Acetylene C_2H_2 and carbon oxides such as CO,CO_2 in addition to no-fault gases like N_2 and O_2 .The majority of gases that are found indicative of faults are also those that are more soluble in Oil. At a pressure of 760 mm Hg and 25^o C temperature, the solubility of gases in Transformer oil is found to be as shown in Table 1.

Table 1. Solubility Of Gases

H_2	7 % by volume
N_2	8.6 % by volume
CO	9.0 % by volume
O_2	16 % by volume
CH_4	30 % by volume
CO_2	120 % by volume
C_2H_6	280 % by volume
C_2H_4	280 % by volume
C_2H_2	400 % by volume

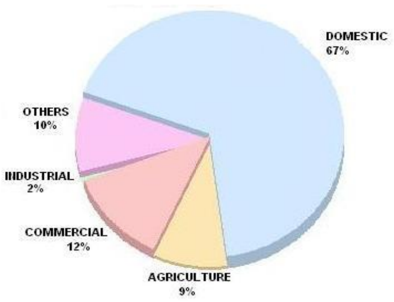


Fig.1.Distribution Growth Since 1957

Over a temperature range 0 to 80 degree Centigrade some gases increase in solubility upto 79 % while others decrease their solubility up to 66 %.**[Wan, Yat How and Marzuki Khalid (1999).]** .By extracting the dissolved gases in the oil, they are separated ,identified and quantitatively determined by DGA method.Eventhough the data from DGA is found to be inconsistent ,since it detects the gases in the oil phase giving the earliest possible detection of an incipient fault, the DGA technique is a very efficient tool.

Thermal Faults

The decomposition of mineral oil (from 150^o C to 500^o C) produces relatively large quantities of the low molecular weight gases, such as H_2,CH_4 and trace quantities of the higher molecular weight gases Ethylene (C_2H_4) and Ethane(C_2H_6).As the fault temperature in mineral oil increases to modest temperatures, the Hydrogen concentration exceeds that of Methane ,but now the temperatures are accompanied by significant quantities of higher molecular weight gases -First Ethane and then Ethylene .At the upper of the Thermal Fault Range, increasing quantities Hydrogen and Ethylene and traces of Acetylene (C_2H_2) may be produced.**[IEEE standards C57.104 TM-(2008)].** The presence of Acetylene suggests a high – temperature fault,perhaps an arc has occurred in the oil in a Transformer, the presence of Methane suggests that – if a fault has occurred- it is a lower energy electrical or thermal fault.

Electrical Faults

a)Low Intensity Discharges: Produce mainly Hydrogen with decreasing quantities of Methane and trace quantities of Acetylene.As the intensity of discharge increases ,the Acetylene, and Ethylene concentrations rise significantly.

b)High Intensity Arcing: As the intensity of Electrical Discharge reaches Arcing or continuing Discharge proportions that produce temperatures from 700^o C to 1800^o C, the quantity of Acetylene becomes pronounced.

Probability of Transformer Failure

In this work Evaluation of possible types of faults is carried out by analysis of separate combustible HydroCarbon Gases. The method used for the analysis using simulink in MATLAB is the Rogers Ratio Method**[R.R.Rogers(1978)]**. The total volume of evolved gas is an indicator of the magnitude of incipient faults.To determine the volume, in gallons, of Total Dissolved Gases Combustible in insulating oil (TDGCv) the following Equation is used.**[IEEE standards C57.104 TM-(2008)].**

TDGCv=FG(V)/1000000;Where FG (Fault Gases) is the sum of H_2, CH_4, C_2H_6, C_2H_4, C_2H_2 and C [micro litres/litre] V is the volume of oil in transformer [litres (gallons)] TDCGv is the total dissolved combustible gas volume [litres (gallons)]

This straight forward method is useful for completely oil-filled (conservator type) transformers with conditions that produce small quantities of fault gas. These conditions warrant continuous monitoring; this fault case volume method continues to be useful as fault conditions enlarge, with the added advantage that it permits continuous monitoring of insulation deterioration in spite of any oil handling activity that includes degasification.

Diagnosis

The diagnostic theories based upon the thermal degradation principles employ an array of ratios of certain key combustible gasses as the fault type indicators. These five ratios are **[Dr.Joseph B.DiGiorgio and, Wan, Yat How and Marzuki Khalid (1999)]**

Ratio 1 (R1) = CH_4/H_2

Ratio 2 (R2) = C_2H_2/C_2H_4

Ratio 3 (R3) = C_2H_2 /CH_4

Ratio 4 (R4) = C_2H_6/C_2H_2

Ratio 5 (R5) = C_2H_4/C_2H_6

The Rogers method utilizes ratios 1,2 and 5. The Roger's method does not depend on specific gas concentration to exist in the transformer for the diagnosis to be valid but the Doernenburg **[IEEE standards C57.104 TM-(2008)]**ratio utilizes ratios 1,2,3 and 4and requires significant levels of gases to be present in order for the diagnosis to be valid. . However Rogers suggests that the method be used only when the normal limits of individual gases(refer Table 2) have been exceeded.

A four level criterion has been developed to classify risks to transform as when there is no previous dissolved gas history, for continued operation at various combustible gas levels. The criterion uses both concentrations for separate gases and the total concentration of all combustible gases**.[IEEE standards C57.104 TM-(2008)].**

Table-2 Limit Concentrations Of Dissolved Gas

Key gas	Concentrations L (Micro litres/litre(ppm))
Hydrogen(H_2)	100
Methane(CH_4)	120
Carbon Monoxide(CO)	350
Acetylene(C_2H_2)	1
Ethylene(C_2H_4)	50
Ethane(C_2H_6)	65

Condition 1 : TDCG below this level indicates the transformer is operating satisfactorily. Any individual combustible gas exceeding specified levels should prompt additional investigation.

Condition 2 : TDCG within this range indicates greater than normal combustible gas level. Any individual combustible gas exceeding specified levels should prompt additional investigation. Action should be taken to establish a trend.Faults may be present.

Condition 3 : TDCG within this range indicates a high level of decomposition Any individual combustible gas exceeding specified levels should prompt additional investigation.Immediate action should be taken to establish a trend .Faults are probably present.

Condition 4 : TDCG exceeding this value indicates excessive decomposition .Continued operation could result in failure of the transformer. Proceed immediately with caution. The Dissolved key gas concentration limits (ppm) for each condition is shown in Table 3.

Evaluation of possible type of fault by the Rogers ratio method:

The Rogers ratio method uses only three ratios(R1,R2,R5) .This method is also based on the thermal degradation principle. Table 4 gives the values for the three key gas ratios corresponding to suggested diagnoses. These ratios according to Rogers are applicable to both gases taken from the gas space and gases extracted from the oil.The fault types given in Table 4have been chosen from the fault types originally suggested by Rogers.

Fuzzy Rogers Ratio System

Fuzzy Rogers Ratio system uses the 5 fault gases which are Acetylene, Ethylene, Methane, Hydrogen and Ethane to determine 9 transformer conditions. Therefore, the structure for the Fuzzy Rogers Ratio system can be illustrated as in **Figure 3** where the ratios are identified as the input parameters while the 9 interpretation results based on the different combination of ratios are identified as the output parameter as listed below.

The test results of DGA for data collected from Electricity Board are tabulated below for a few random samples. The remarks predicts suspected occurrence of Thermal Fault above 100^0C due to Overheating. Out of the 551 samples collected from various Transformers located at different substations 329 samples are no fault data and 137 are recommended resampling by the TNEB Test Lab. These 137 samples were tested with Rogers Ratio Simulink and Fuzzy Rogers Ratio System and the results are compared.

Table 3- Dissolved Key Gas Concentrations

Status	Dissolved Key gas concentration limits [µL/L(ppm)]							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG [a]
Condition1	100	120	1	50	65	350	2500	720
Condition2	101-700	121-400	2-9	51-100	66-100	351-570	2500-4000	721-120
Condition3	701-1800	401-1000	10-35	101-200	101-150	571-1400	4001-10000	1921-4630
Condition4	>1800	>1000	>35	>200	>150	>1400	>10000	>4630

[a]TDCG value does not include CO_2 ,which is not a combustible gas.

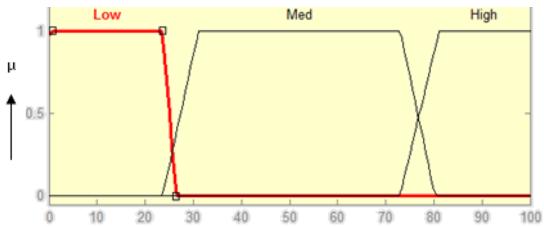
Table 4-Rogers Ratio For Key Gases

Case	**R2** **C2H2/C2H4**	**R1** **CH4/H2**	**R5** **C2H4/C2H6**	**Suggested fault diagnosis**
0	<0.1	>0.1 to <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low energy density arcing-PD
2	0.1 to 3.0	0.1 to 1.0	>3.0	Arcing-High energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal<700deg
5	<0.1	>1.0	>3.0	Thermal>700deg

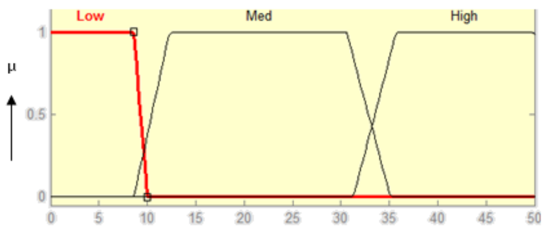
Rogers Simulink Model in MATLAB is shown in **Fig .2.**

Fault code	Fault Type	Ranges of gas ratio C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
0	No fault	<0.1	0.1-1.0	<1.0
1	Low energy partial discharges	<0.1	<0.1	<1.0
2	High energy partial discharges	0.1-3	<0.1	<1.0
3	Low energy discharges	>0.1	0.1-1.0	>1.0
4	High energy discharges	0.1-3	0.1-1.0	>3.0
5	Low temperature fault 150°C	<0.1	0.1-1.0	1.0-3.0
6	Low temperature fault 150-300°C	<0.1	>0.1	<1.0
7	Medium temperature fault 300-700°C	<0.1	>0.1	1.0-3.0
8	High temperature fault>700°C	<0.1	>0.1	>3.0

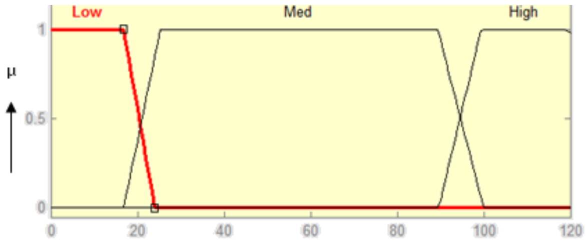
The Ratios are fuzzified**[Zimmerman,H.J. (1986) and R.Naresh,Veena Sharma Vashisth, and Manisha (2008]**using the following Linguistic variables and membership functions as shown below.



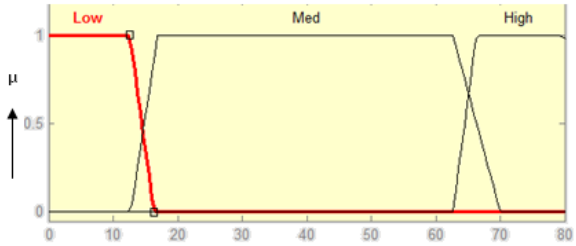
Methane



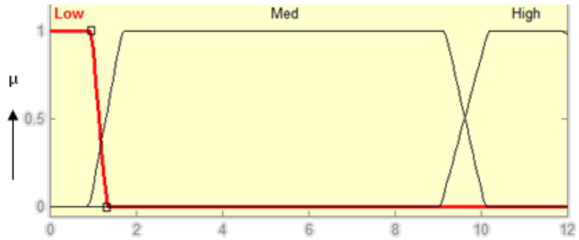
Ethane



Ethylene

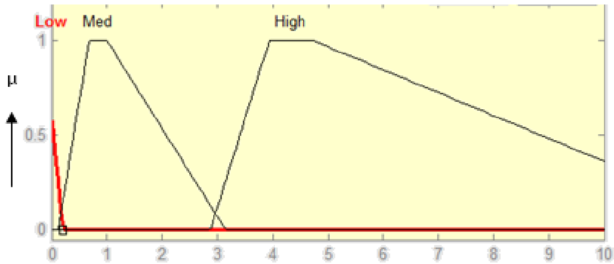


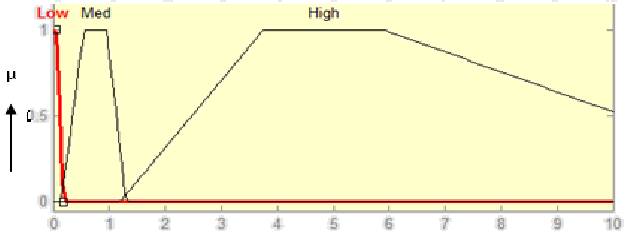
Acetylene



Hydrogen

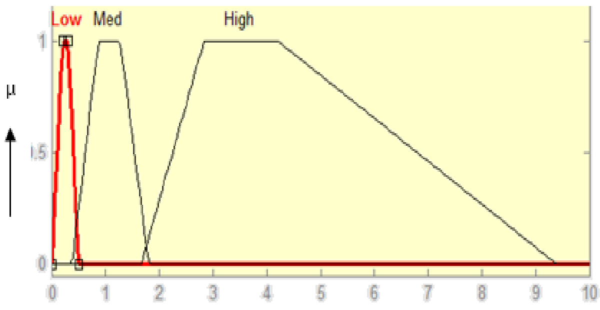
FIG.4 – MEMBERSHIP FUNCTION OF ATTRIBUTES



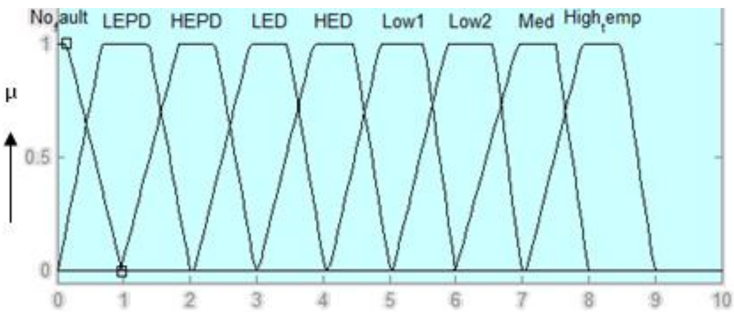


Input variable R2=C_2H_2/C_2H_4

Input variable R1=CH_4/H_2



Input variable R5=C_2H_4/C_2H_6



OUTPUT VARIABLES= OUTPUT

FIG.5 INPUT AND OUTPUT VARIABLES

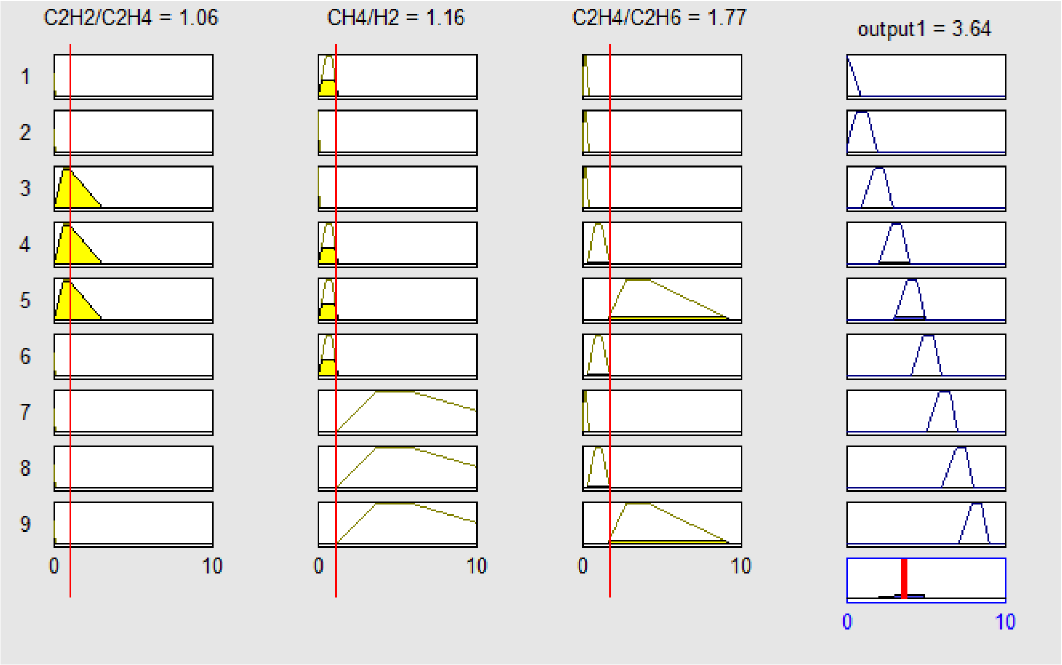


FIG.6 SAMPLE TEST OUTPUT FOR R1=1.16; R2=1.06; R5=1.77

TABLE-5 HYDROCARBON GASES FROM DGA DATA-Date of Commissioning 08.11.2005

HC Values in ppm 16 MVA,110/11kV	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO_2	CO	Remarks By Lab Expert
Sample I-03.01.2006	46	168	37	286	2	840	-	Thermal Fault of above 100^0C Due to Overheating
Sample II-17.01.2006	64	224	49	376	2	1164	-	
Sample III-06.02.2006	38	219	52	377	1	1340	-	
Sample IV-16.03.2006	29	189	75	353	2	1454	-	
Sample V-11.04.2008	14	67	42	111	0	1223	-	Resample
Sample VI-07.08.2008	22	94	43	138	3	1823	-	
SampleVII-27.04.2009	25	96	50	158	6	1964	-	Satisfactory

IV.RESULTS

TABLE-6 RESULTS

Conventional Rogers Ratio Simulink Model	Fuzzy Rogers Ratio System
Samples taken: 137 Consistent : 83 Inconsistent : 54 Success : 64 Failure : 19 % of Success : 80 Efficiency : 77	Samples taken: 137 Consistent : 95 Inconsistent : 42 Success : 87 Failure : 08 % of Success : 91 Efficiency : 92

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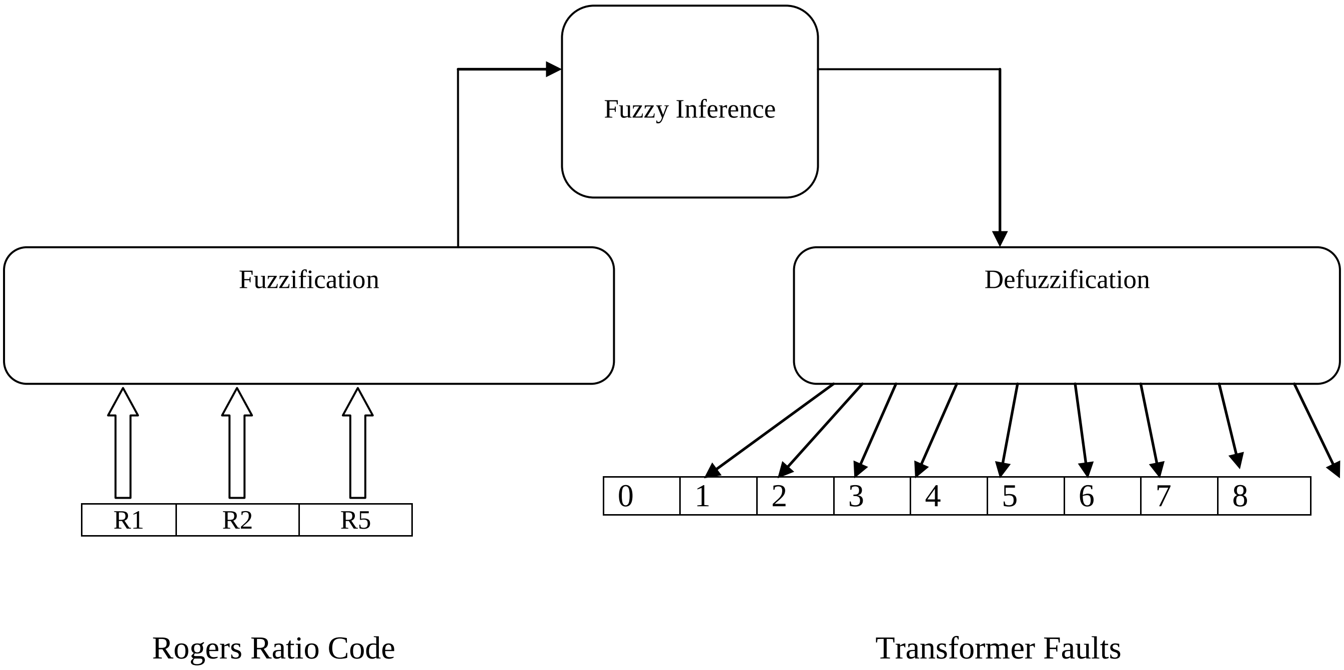

FIG.3 FUZZY ROGERS RATIO SYSTEM

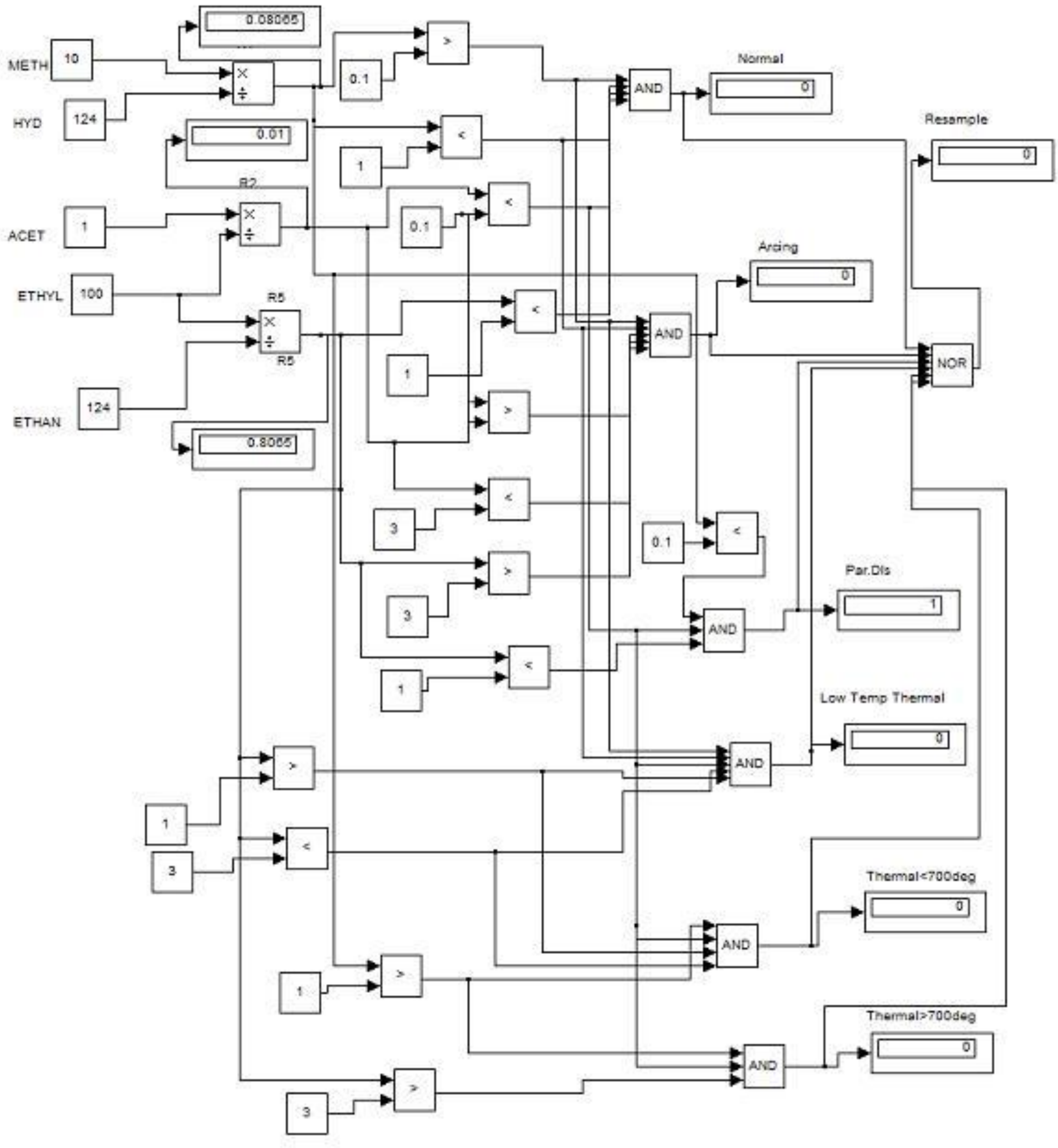

FIG .2. ROGERS SIMULINK MODEL IN MATLAB

Indra Getzy David received her B.E.[EEE] and M. E. [CSE]degrees from Govt. College of Technology Coimbatore, then affiliated to the University of Madras and Bharathiar University ,South India in 1982 and 1990, respectively. She worked in the Public Works Department as an Assistant Engineer [electrical] for a period of an year where she was doing estimation and execution of the Electrical Works for the Bharathiar University Buildings Division in Coimbatore, TamilNadu , SouthIndia. Presently she is an Associate Professor in the Department of Electrical Engineering, Govt. College of Engineering Tirunelveli, South India. To her credit she has nearly three decades of Teaching Experience. She is interested in the areas of Computer
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