

Fuzzy Logic Based Coolant Leak Detection

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Abstract- Liquid is used as coolant in transformer, in which leak detection is important. In this case condition monitoring of leak detectors are used to detect the liquid while leaking. It is important to monitor the leak detectors also. To detect the liquid leak health monitoring of leak detector is analyzed with fuzzy logic based approach. The detector works on the principle of conductivity, which is based on change in resistance of detector. It is connected through circuit, which gives the status about leak in transformer and the cable status. There are four conditions of leak detection namely, Leak. No Leak (Healthy). Cable Open and Cable Short. These leak detectors are directly attached with transformer container wall. The outputs of these remotely located leak detectors, are connected to electronic hardware system, to perform the processing. In this paper, the leak detector design, simulation and processing of sensor data using fuzzy logic is being discussed. For design and simulating leak detector setup with electronics hardware, Proteus simulation software is used. The fuzzy logic system was implemented in the simulated leak detector system, and the results are detailed in this report.

1. INTRODUCTION

In transformer, liquid is used as coolant. To detect the leak in transformer, wire type leak detectors are used. It is working on conductivity principle. These leak detectors are directly attached with liquid pipe lines, tanks and other capacities. The outputs of these remotely located leak detectors are connected to electronic hardware system, to perform the processing. These leak detectors work on the principle of conductivity and it is responding to leak in process. The actual conductivity based detector circuit gives the status about leak in liquid transformer and the status of the detector itself. An alarm has to be generated through SCADA system in sub station, when leak occurs in process. The alarm and detector status are communicated to the control room through the Ethernet interface from electronic hardware system.

Power facilities must perform continuously, often in extreme environments. Properly sized and configured, high quality transformer liquid coolers play a vital role in

maintaining safe, efficient, and reliable electricity production. Overheating can shorten the transformer's life, and in severe cases, could lead to serious and costly damage or even destruction of a transformer. Cooling the transformer is affected by the varied conditions that can occur, and special care is needed to design cooling systems that actually reflect the existing ambient conditions on the site.

In common Fuzzy logic techniques are used for condition monitoring and fault diagnosis application (1), its ensuring that the system availability and reliability. As part of the fault diagnosis, fault detection and fault classification are analyzed. The development of fuzzy logic systems with algorithms based on Diagnostic matrix and data validation (2-3). The multi stage condition monitoring system (4), deals for different states of the detector condition also explained. Optimization studies were done for wireless sensor network operations (5). In this paper, we study leak detector condition monitoring by simulating the inputs and observes the corresponding output at proteus simulation software. This leak detector data are fed to the fuzzy logic based system and validated the corresponding condition of the leak detector state. The fuzzy logic system was implemented in the simulated leak detector system, and the results are detailed in this paper.

2. THEORY

Wire Type Leak Detector is assembled using nickel wire and specially shaped ceramic beads. This assembly is tied below the transformers. Normally the nickel wire is not making electrical contact with the transformer. When liquid leaks it bridges the gap between the nickel wire and the pipe line thus making the electrical connection between the wire and the transformer. This is sensed by electronic circuits.

The Sensing mechanism for a single channel comprises of three resistors, cables and detectors. The two terminals of the switch remains open for healthy condition and get shorted when the liquid leak is detected. Fixed resistors of 100 ohms and 470 ohms are connected to the cables in the field. A detector card is measured depending upon the input resistance in the field based on the condition tested. The Sensing mechanism is similar for all the detectors in

the system. The leak detector output signals from the field are connected to the leak detector card through electrical wires.

The leak detector should provide the four conditions at the input of the signal conditioning circuit. They are i. When there is no leak (Healthy Condition), the total resistance will be 570 ohm and the voltage at the terminals is 4.6V. ii. When there is leak, the resistance will be 1000 ohm and the voltage at the terminals is 1.09V. iii. When there is Cable short, the resistance will be 50 ohm (approx) and the input potential is measured to be 0V. iv. When there is Cable open, the resistance will be more than 10 K ohm and the input potential is measured to be 12V.

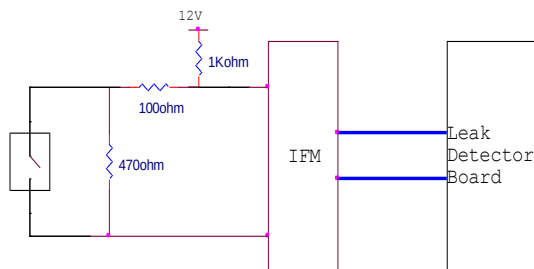


Fig.1. Schematic of Leak detector

TABLE 1 CONDITION OF THE LEAK DETECTOR

S.No	Voltage (V)	Resistance (Ohm)	Digital Output	Condition
1	0-0.6	50	0001	Cable Short
2	0.65-1.9	100	0010	Leak
3	3.6-6.3	570	0100	No Leak Healthy
4	6.6-10	>10K	1000	Cable Open

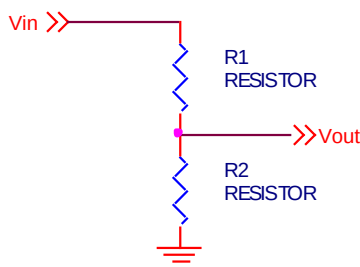


Fig.2. Resistor network in leak detector circuit

The output voltage V_{out} is related to V_{in} as follows: Therefore the input voltage to the electronics, by voltage divider rule,

$$V_{out} = (R_2 / (R_1 + R_2)) * V_{in} \quad (1)$$

Case i. Healthy and No Leak Condition

When there is no leak and the sensor is healthy, the switch in the circuit remains open and the resistance appearing across the output V_{out} is, $R = 570$ ohms
 $V_{out} = (570 / (1000 + 570)) * 12 = 4.3V$
Hence when the condition is healthy and no leak the voltage lies in the range 3.6 V to 6.3 V.

Case .ii Leaky

When there is a Liquid leak in the transformers, the switch gets closed and the resistance 470 ohms in parallel with it gets shorted and the resistance appearing across the output voltage V_{out} is, $R = 100$ ohms. Therefore the input voltage V_{out} to the electronics, by voltage divider rule,
 $V_{out} = (100 / (1000 + 100)) * 12 = 1.09V$.
Hence when the condition is leaky the voltage lies in the range 0.65 V to 1.9 V.

Case.iii Cable Short

When the cable of the Leak detector gets shorted, the resistances 100 ohms and 470 ohms get shorted and the Resistance appearing across the output voltage V_{out} is, $R = 0$ ohms. But a very less value of resistance of the order of 50 ohms appears across the output which is the characteristic resistance of the Cable. Therefore the input voltage V_{out} to the electronics, by voltage divider rule,
 $V_{out} = (0 / (1000 + 0)) * 12 = 0V$.
Hence when the condition is Cable short the voltage lies in the Range 0 V to 0.6 V.

Case iv. Cable Open

When there is an open circuit in the cable of the Leak detector, a very large resistance of value greater than 10 Kohms appears across the output V_{out} . Therefore the input voltage V_{out} to the electronics, by voltage divider rule,
 $V_{out} = (10000 / (1000 + 10000)) * 12 = 11V$, and the output voltage is in the order of 12V.
Hence when the condition is Cable open the voltage lies in the Range 6.6 V to 10 V.

3 FUZZY LOGIC FOR LEAK DETECTION

To detect the leak and condition monitoring, leak detector data is analyzed with fuzzy logic based approach. This methodology involves artificial intelligence and it is a rule based model. In the case of leak detection, in accuracy of sensed data, event conditions and sensor group formation are managed by fuzzy logic approach. The fuzzy set: $A = \{(x, \mu_A(x)) | x \in X\}$
Where μ allows various degrees of membership, its maps X to M ; If $M = \{0,1\}$ then A is non fuzzy or Boolean. The

fuzzy sets are need little computational power compare to HMM, few data samples are required to form the rule, which is operator defined and describing the problem is easy in this approach.

Fuzzy logic system is a nonlinear mapping of input feature to an output. The mapping of leak detector inputs into output status or conditions are performed. The following basic components like rules, fuzzifier, inference engine and defuzzifier are used in this fuzzy logic system.

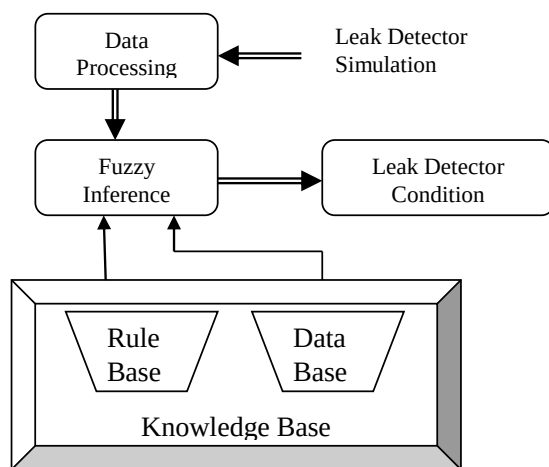


Fig.3. Fuzzy logic model

In this case, Linguistic variables are the output of the leak detectors – voltage and resistance represented by their numerical values. To quantify the linguistic variables, fuzzy membership functions are used. To make logical expression and connection with linguistic variables, logic operators are used. Logical expressions form the fuzzy rule base.

TABLE 2 LINGUISTIC VARIABLES

Variables	Very Low	Low	Normal	High
Resistance	50	100	570	>10K
Voltages	0-0.6	0.65-1.9	3.6-6.3	6.6-10
Digital	0001	0010	0011	1000

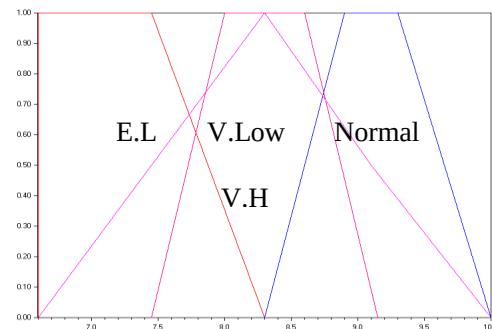


Fig.4. Linguistic Variables for leak detector Voltage

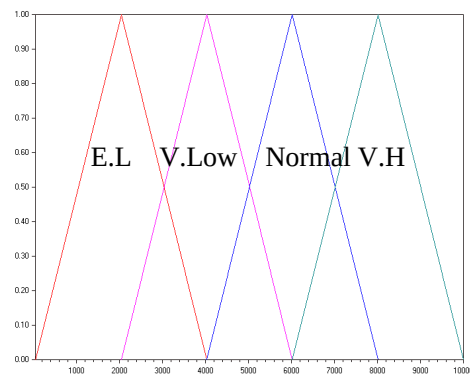


Fig.5. Linguistic Variables for leak detector Resistance

Linguistics symbols

Detector status is considered as Linguistic symbols, which are namely: Cable Open, Cable Short, and Healthy: No Leak and Leak.

Rules

Rule 1:

IF Detector Resistance IS Normal
AND Detector Voltage IS Good
THEN Health IS Present

Rule 2:

IF Detector Resistance IS High
AND Detector Voltage IS Very Low
THEN Leaky IS Poor

Rule 3:

IF Detector Resistance IS Low
AND Detector Voltage IS Extremely Low
THEN Health IS Present

Rule 4:

IF Detector Resistance IS Very High
AND Detector Voltage IS High

THEN Health IS Present

The inference engine acquires the set of inputs from fuzzifier and transforms the output through defuzzifier with control of fuzzy rule base. Decision making based on Fuzzyfication, evaluation of rules, Inference, combination (max operator) and Defuzzyfication (Centre of area). Inference criteria for appropriate aggregation operators, Axiomatic strength(the less limiting the better), Empirical fit (appropriate models for real systems) and numerical efficiency.

4. EXPERIMENTAL SIMULATION

In this paper, the leak detector design and simulation and processing of sensor data using fuzzy logic is developed. The circuit acquires and scans the analog input signals. The proteus simulation is shown in fig.6. ADC converts the analog signals into digital form, compares with the predetermined values and stores in memory. The sensed signal is digitized, compared with the preset values stored in memory and output is detected based on the above conditions. This condition monitoring is analyzed with fuzzy logic approach, which is rule base model. For design and simulating leak detector setup with electronics hardware, Proteus simulation software is used.

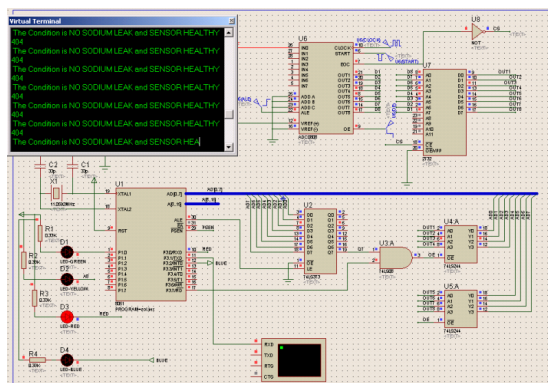
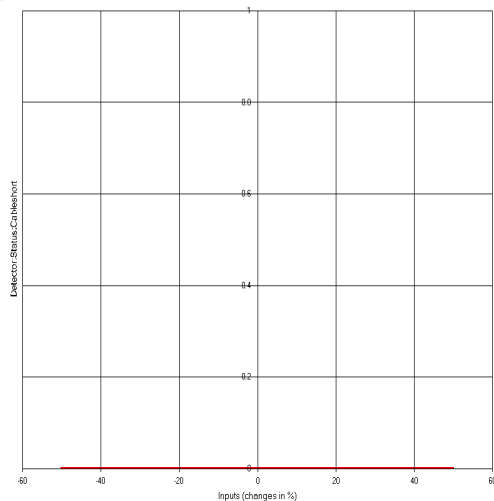
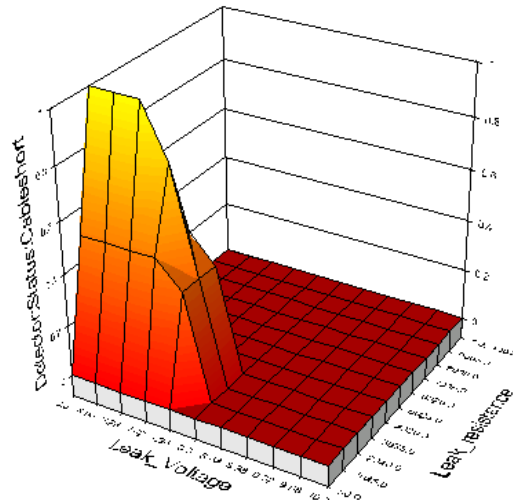


Fig.6. Proteus simulation for Sensor healthy: No leak



The system has the capability to indicate the condition of leak detector. The operator sitting at the control room can get information about the status of Liquid in the Transformers.



5. RESULTS AND DISCUSSION

The fuzzy logic system was implemented in the simulated leak detector system, and the results are discussed in detail.

Figure

Fig.7. Sensitivity & Transfer function for Cable short

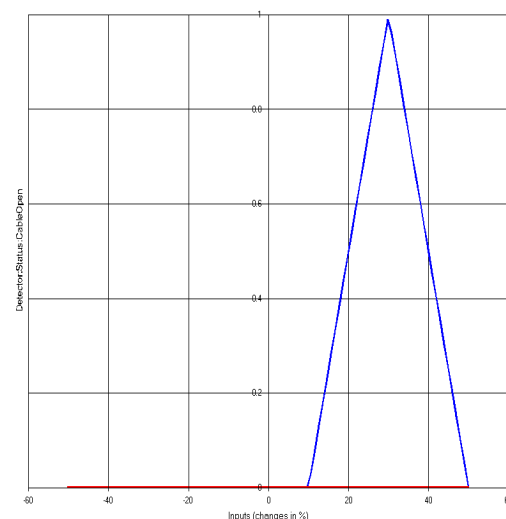
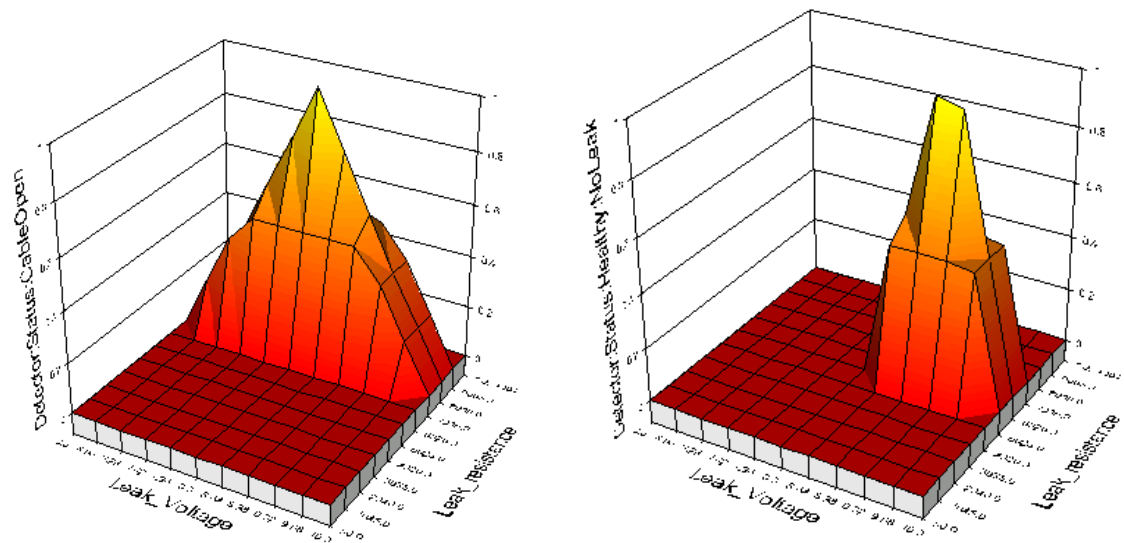


Fig.8. Sensitivity & Transfer function for Cable Open



Figure

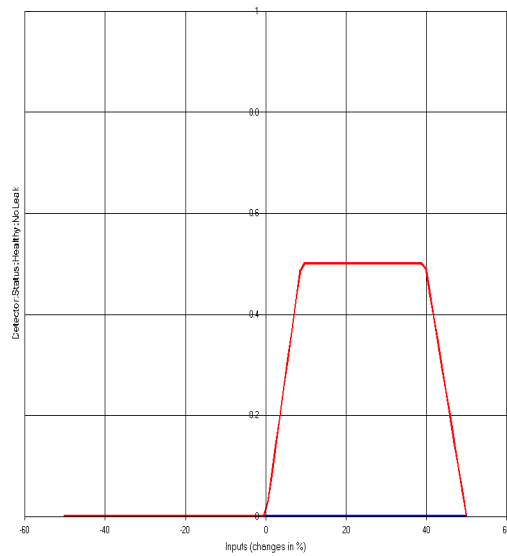


Fig.9. Sensitivity & Transfer function for Healthy: NoLeak

Figure

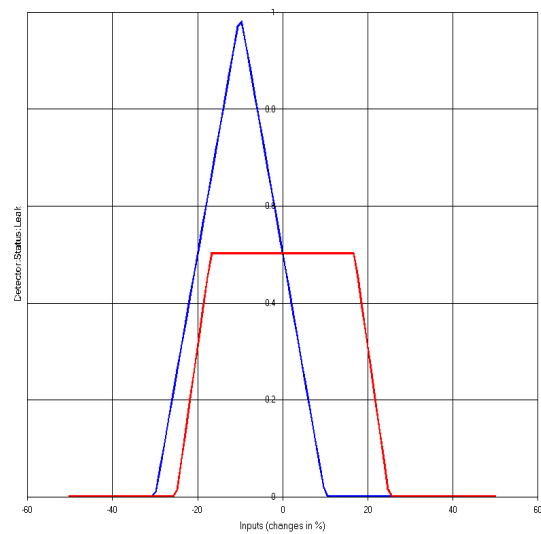
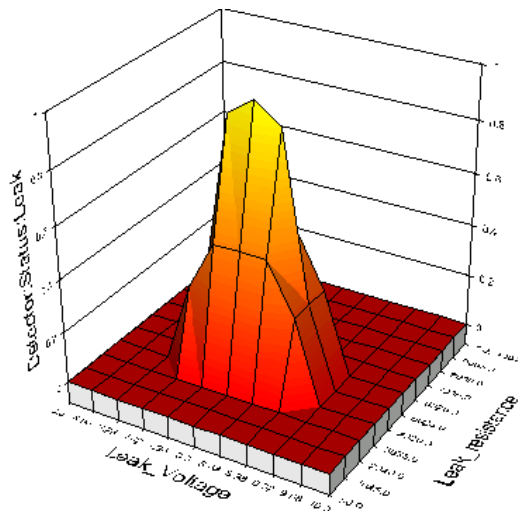


Fig.10. Sensitivity & Transfer function for Leak



For every state of leak detector, the sensitivity was plotted in the graph for leak detector resistance and output voltage value, which are input to the fuzzy model. For this leak detector data validation, Transfer function was applied and observed the responses in 3D profile.

The data analysis error was calculated for all the state of the leak detector. In this error calculation Actual value and set point values are used to find the Mean absolute Error (MAE), Mean Square Error(MSE) and Root Mean Square Error(RMSE), all the errors zero.

The Errors for each state of the leak detector was compared with actual error and rated error. From this matrix of confusion is framed. To find the leak detector conditions based on the fuzzy rule base a card model is used and the output was received in chart form and file format.

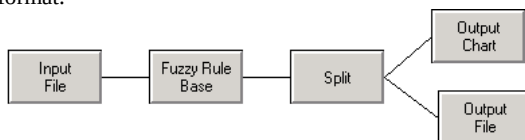


Fig.11. Fuzzy rule base card analysis for leak detector

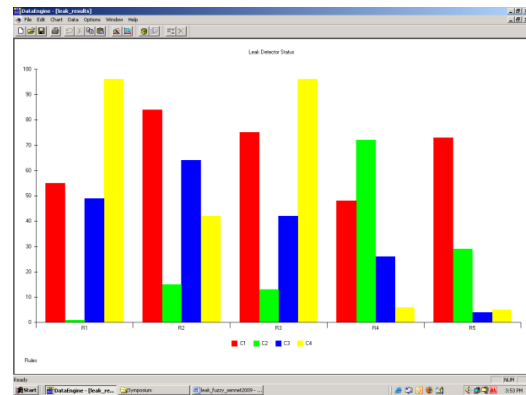


Fig.12. Card analysis output for rule based model

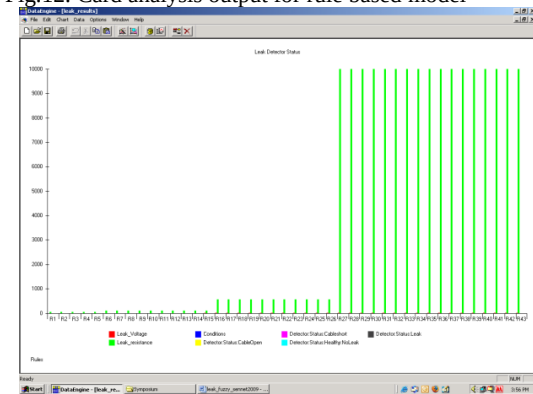


Fig.13. Fuzzy rule base card analysis output

6. CONCLUSIONS

The Fuzzy logic based leak detector condition monitoring is demonstrated and their functional characteristics are discussed. The hardware based simulation results using Proteus was verified with fuzzy logic model based approach for leak detection condition monitoring applications, instead of bulk hardware based solutions. This method is more suitable for leak detector data validation using model analysis for error calculation and forming the matrix of confusion. The data card model gives output in the form of chart and file format, which are useful to find the state of the leak detector vs rule based model. As a result the fuzzy logic based condition monitoring for liquid leak detection can be implemented in future.

7. REFERENCES

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