Fuzzy Logic System for Rectification of Erroneous Measurements Caused by Human Intervention in HPFF Installation

Maciej Wenerski, Radosław Tomala, Paweł Marciniak, and Rafał Kotas

***Abstract*—The goal of this paper is to present a solution for detection of human interference in leak detection system for HPFF installation. This solution is based on fuzzy logic. In HPFF systems, that were base of this work, three different types of human interference were observed. For each of them separate systems were developed. This paper describes different types of possible human intervention and solutions for its detection.**

***Index Terms*—fuzzy logic, high-pressure fluid-filled cables, *HPFF*, detection, expert system**

I. Introduction

NOWADAYS in urbanized areas of North America HPFF (High Pressure Fluid Filled) cables are used on a large scale. Such installations may have different construction - among others there are installations with oil oscillation, in which the pumping stations are located at both ends of the circuit. One of the circuits of this type has been equipped with an oil leak detection system based on network of sensors placed along the entire perimeter. The use of such a system, given the large number of sensors, entails high costs and the need for ongoing maintenance of the installation. Therefore it is deliberate to build less complex, thus less costly system, which would also provide at least a comparable level of detection.

Currently work on such system based on artificial intelligence techniques is conducted. It is based on the measurement data typically available in HPFF installation. Authors of this system encounter many problems during work. One of these problems is that the measurement data can be disrupted by human interference during variety of different maintenance works, or because of changes in scaling factors. Such interference may introduce false data into the system. Such data can lead to erroneous operation of the system, although it is not associated with the physical phenomena occurring in the system. Therefore, it is necessary to use procedures for detecting and correcting erroneous data introduced by described interference.

This paper concerns the module responsible for the detection and correction of such data. This solution is based on fuzzy logic. It is one of the polyvalent logics, extending the classical approach of bivalent logic. The authors of a leak detection system have a set of the measurement data from two different installations – with and without oil oscillation. Both circuits are equipped with different sets of sensors and therefore for each of the installations different measurement data are available. In these installations three different types of human interference were observed. For each of them separate systems were developed. Such approach is caused by the variety of data related to different types of human interference in the system. Developed systems can detect the following types of human interference: volume change of gas above the oil in the tank, change of the scaling factors and change of the flow level caused by pumping oil to a different installation.

II. Manual Change of the Volume of Gas Above the Oil in the Tank

This type of interference occurred in the case of installation no.1 – without oil oscillation. During the monitoring of the system nitrogen was pumped into the tank of oil twice. Such interference was caused by drop of nitrogen pressure above the oil (resulting from the earlier decrease of the current value), which in turn led to a reduction in the volume of oil in the pipe. Manipulation of the gas pressure above the oil is the only way to intervene, which was noticed during normal operation of system no.1. To ensure proper operation of leak detection system it is necessary to detect the above cases.

System based on fuzzy logic designed for detection of such situations is presented below. Input values of the system are: short term (over 100 samples) rate of change of gas pressure (V_{pst}), long-term rate of change of gas pressure, defined as changes of the average values for 2000 samples (V_{plt}) and short-term (over 100 samples) rate of change of current (V_{cst}). In this installation measurements of all parameters are performed at the same time with constant frequency

M. Wenerski, R. Tomala, P. Marcinak and R. Kotas are with the Department of Microelectronics and Computer Science, Technical University of Łódź (TUL), Wólczańska 221/223, 90-924 Łódź, Poland (e-mails: mwenerski@dmcs.pl, tomala@dmcs.pl, pmarciniak@dmcs.pl, rkotas@dmcs.pl).

(measured every minute). Therefore, velocity of change will be equal to the level of change. The output of the system is the probability of human intervention (MP). Membership functions for inputs and output are presented below.

- V_{pst}: 0.0925 and 0.037 are respectively half and twice the average gas pressure changes per 100 samples multiplied by 5.
- V_{cst}: 90.5 and 362 are respectively half and twice the average current value changes per 100 samples multiplied by 5.
- V_{plt}: 0.5 and 2 are respectively half and twice the average change in mean values (per 2000 samples) of gas pressure multiplied by 5.

Five times the average pressure change of gas per 100 samples, the average current value changes per 100 samples and changes of mean gas pressure values are the for which the levels of membership – for sets SMALL and BIG are equal and amount to 0.5.

Presented system is based on following rules:

- IF V_{pst} IS BIG AND V_{cst} IS SMALL AND V_{plt} IS SMALL THEN MP IS BIG
- IF V_{pst} IS BIG AND V_{cst} IS BIG AND V_{plt} IS SMALL THEN MP IS SMALL
- IF V_{pst} IS BIG AND V_{cst} IS SMALL AND V_{plt} IS BIG THEN MP IS SMALL
- IF V_{pst} IS BIG AND V_{cst} IS BIG AND V_{plt} IS BIG THEN MP IS SMALL
- IF V_{pst} IS SMALL THEN MP IS SMALL

Human interference in the system always causes a rapid change in pressure of nitrogen above the oil (V_{pst} value in the system). A large value of V_{pst} does not have to be the result of human intervention in the system if it is combined with a large short-term increase of current (current change and the oil pressure shows a fairly good short-term correlation but not long-term) or high long-term growth trend of pressure over the oil. The system uses the last of maximum method for defuzzification.

Solution presented above correctly detects the human interaction cases occurred in the system. The figure below shows the detected cases of human intervention (graphs have been scaled to show the dependence of current and nitrogen pressure).

For the correct operation of the system, it was necessary to introduce an additional check of the value of current at the time of detection of human intervention. Otherwise the system detects a human interference in the case of longer power outages. This is because, when the current drops to zero and remains at that level for some time, the value of the gas pressure decreases rapidly, despite the fact that there are no changes in current values.

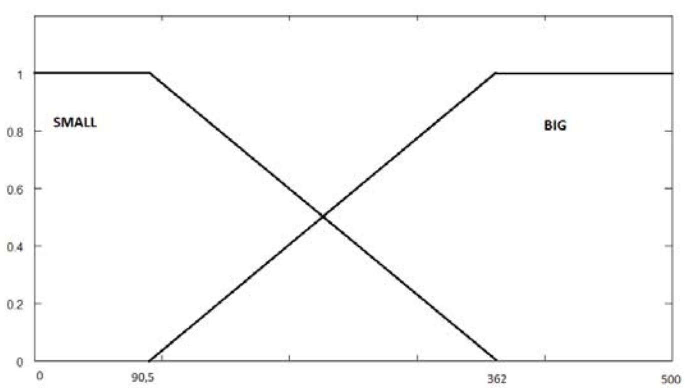

Fig. 1. Membership functions for input V_{pst}.

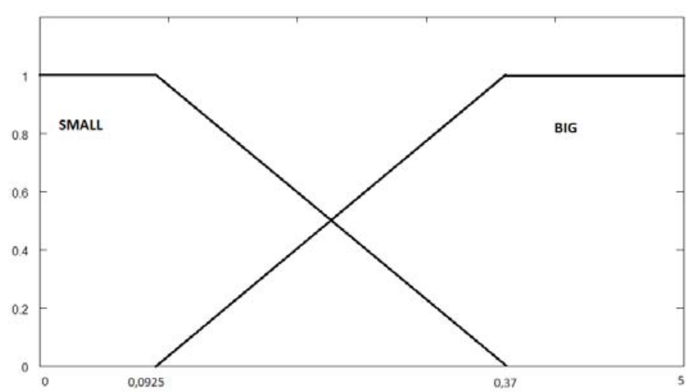

Fig. 2. Membership functions for input V_{cst}.

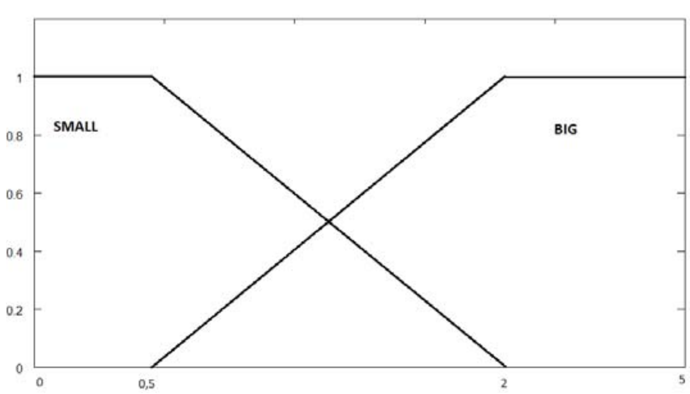

Fig. 3. Membership functions for input V_{plt}.

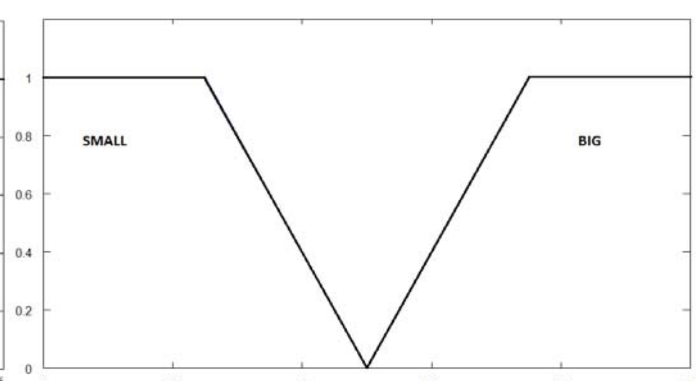

Fig. 4. Membership functions for output.

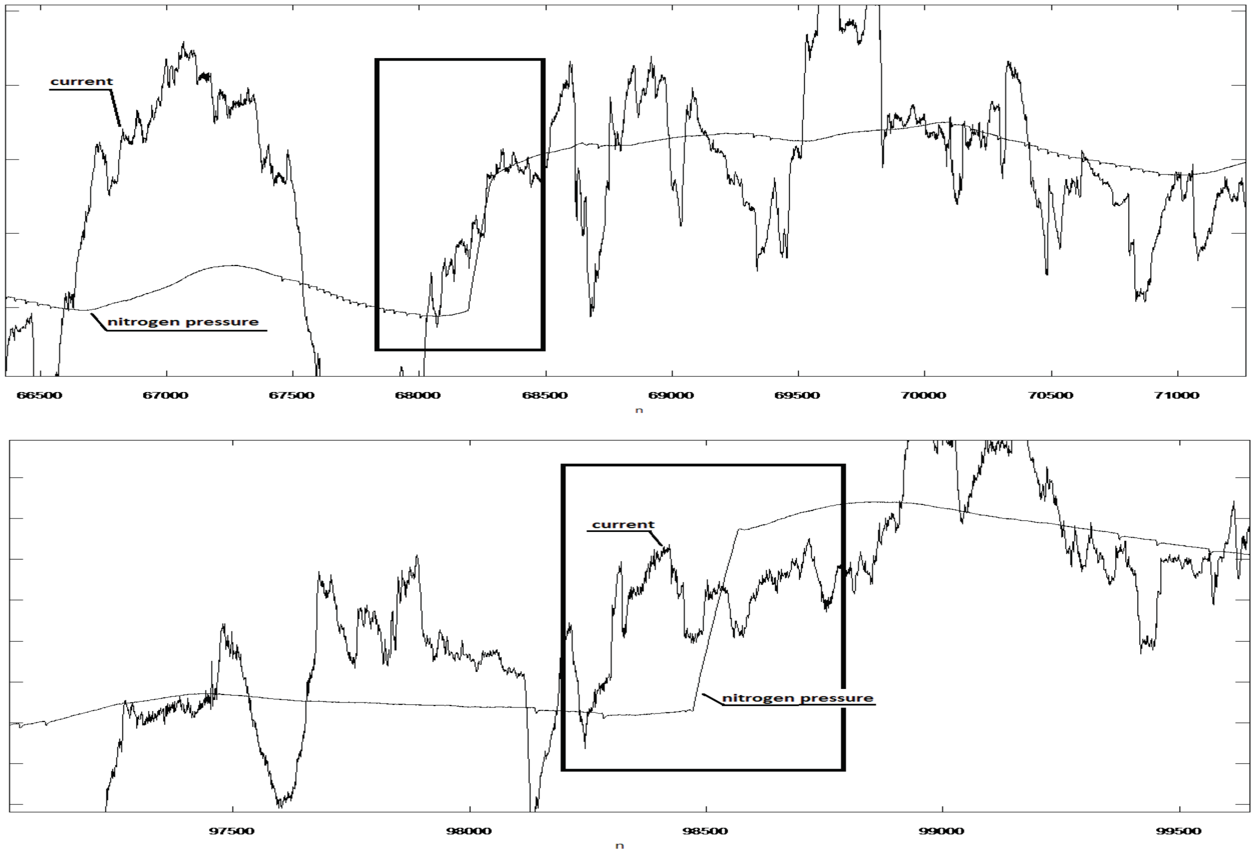

Fig. 5. Detected cases of human interference (nitrogen pressure).

III. Change of the Scaling Factor

This type of interference occurred in case of installation no.2. It concerned the scaling factor changes for ambient temperature sensor (ratio was changed from ×10 to ×1).

To detect this type of human interaction following system based on fuzzy logic was used. Input values of the system are: R_{n1} defined as value of sample n+1 and n ratio for value of sample n different from 0 and 100 otherwise, R_{n2} defined as value of sample n+2 and n+1 ratio for value of sample n+1 different from 0 and 100 otherwise and R_{av} defined as the ratio of mean values of 10 samples prior and 10 samples following n-sample.

Presented system is based on following rules:

- IF R_{n1} IS (BIG OR SMALL) AND R_{n2} IS MEDIUM AND R_{av} IS (BIG OR SMALL) THEN MP IS BIG
- IF R_{n1} IS (BIG OR SMALL) AND R_{n2} IS (BIG OR SMALL) AND R_{av} IS (BIG OR SMALL) THEN MP IS SMALL
- IF R_{n1} IS (BIG OR SMALL) AND R_{n2} IS MEDIUM AND R_{av} IS MEDIUM THEN MP IS SMALL
- IF R_{n1} IS (BIG OR SMALL) AND R_{n2} IS (BIG OR SMALL) AND R_{av} IS MEDIUM THEN MP IS SMALL
- IF R_{n1} IS MEDIUM THEN MP IS SMALL

Membership functions for all inputs look identical and are shown in the figure below.

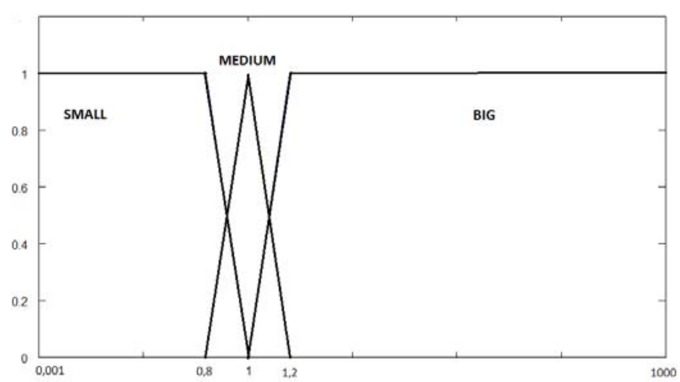

Fig. 6. Membership functions for all inputs.

The output of the system is the probability of human intervention (MP). Membership functions for output are the same as in the previous system (Fig. 4.). In the case of sensor scaling value R_{n1} will belong to the set SMALL or BIG (depending on whether the scaling factor will be greater or smaller than unity). However, since the situation is not necessarily the result of rescaling the sensor, it is necessary to further verify the value of R_{n2}, which in the case of scaling should be in the range MEDIUM set and R_{av}, which verifies that a significant change in the value is not a long-term trend.

The system uses the last of maximum method as a defuzzification mechanism. System presented above works correctly.

IV. PUMPING OIL TO ANOTHER INSTALLATION

This type of interference occurred in the case of installation no.2. As a result there was a change in the level of oil flow recorded in the system.

The following is a system for detecting such cases. Input values of the system are: V_{st} defined as short-term change in the level of flow, V_{av} defined as a change between the average flow levels for the five samples before and after the test sample and V_{lt} defined as long-term change in the flow level. Because of oscillating nature of flow changes second installation flow level is defined as average for adjacent minimum and maximum values, long-term change is understood as a change in the average levels for 10 samples.

Presented system is based on following rules:

- IF V_{st} IS BIG AND V_{av} IS BIG AND V_{lt} IS BIG THEN MP IS SMALL
- IF V_{st} IS BIG AND V_{av} IS BIG AND V_{lt} IS SMALL THEN MP IS BIG
- IF V_{st} IS BIG AND V_{av} IS SMALL AND V_{lt} IS BIG THEN MP IS SMALL
- IF V_{st} IS BIG AND V_{av} IS SMALL AND V_{lt} IS SMALL THEN MP IS SMALL
- IF V_{st} IS SMALL THEN MP IS SMALL

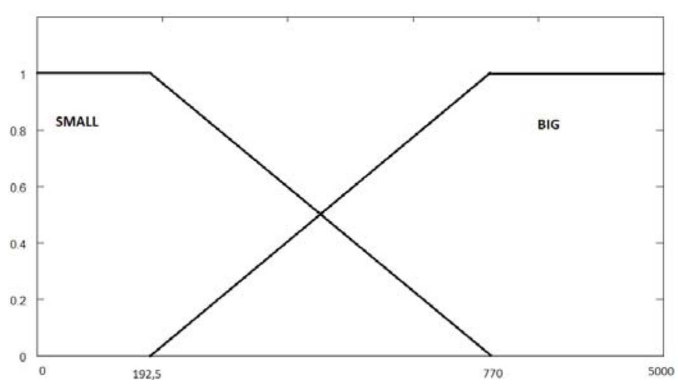

Fig. 7. Membership functions for inputs V_{st} and V_{av}.

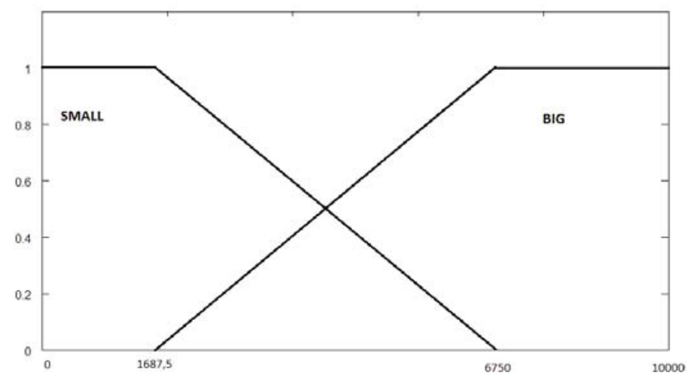

Fig. 8. Membership functions for input V_{lt}.

Human interference always results in big short-term change of flow, but not always big short-term change of flow has to be the result of human intervention. Therefore it is necessary to further verify whether or not this is only a momentary fluctuation caused by different factors and whether the size of the short-term change is not reflected in long-term trend. Membership functions for inputs are presented above.

Limits for fuzzy sets were designated as follows:

- V_{st} and V_{av} : 192.5 and 770 are respectively half and twice the average change in the level of flow multiplied by 5.
- V_{lt} : 1687.5 and 6750 are respectively half and twice the average change in mean changes in the flow level multiplied by 5.

Five times the average changes and mean changes in flow rate are the values for which membership level to sets SMALL and BIG are equal and amount to 0.5. The output of the system is the probability of human intervention (MP). Membership functions for output are the same as in the case of the first system (Fig. 4.). Centre of gravity method was used for defuzzification.

Tests on the available data showed that system presented above is working properly. Figure shown below presents identified cases of human intervention (bold rectangles).

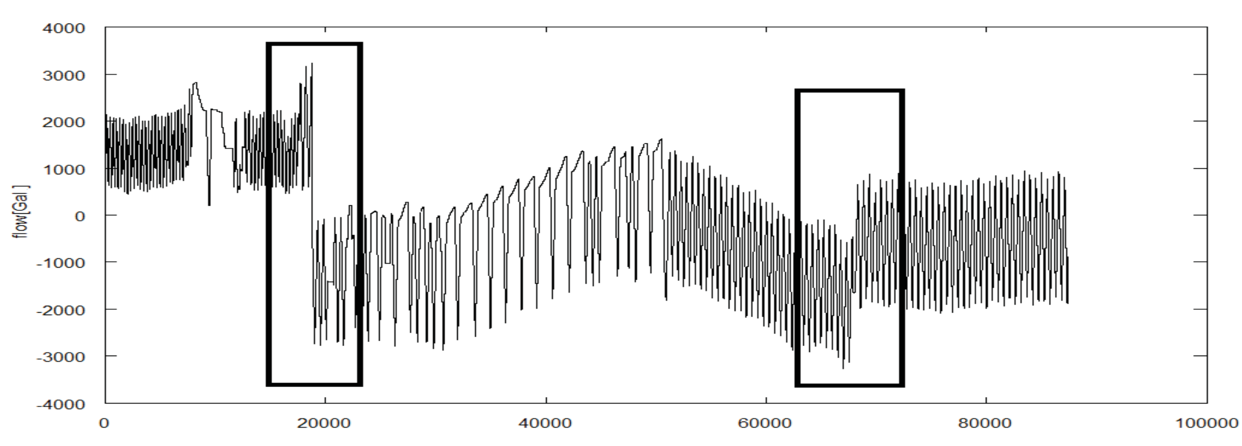

Fig. 9. Detected cases of human interference (flow).

V. Summary

All systems presented above are the final versions. During design process different solutions were tested. It was clear from the begging that for all sets (besides MEDIUM set in system detecting change of scaling factors) left and right open membership functions must be used taking into account nature of these sets. In these cases sigma, L-type, gamma membership functions were tested in different combinations, for mentioned above MEDIUM set gauss, T-type and pi-type functions were tested. In all cases results were comparable and finally as it is presented in systems' description T-type, gamma and L-type functions were used.

All systems presented above works correctly. It was proved based on tests performed on measured data and additional information provided by the operator. Including system described in this paper, leak detection system allows detecting all cases of human interference and avoiding erroneous operation of the system.

References

[1] Piegat A. „Modelowanie i sterowanie rozmyte". Akademicka Oficyna Wydawnicza EXIT, 1999.

[2] Kosko B. "Fuzzy Thinking: The New Science of Fuzzy Logic". Hyperion, 1994

[3] Reza Ghafurian, Russell N. Dietz, Thomas Rodenbaugh, Juan Dominguez, Noah Tai. "Leak Location in Fluid Filled Cables Using the PFT Method." IEEE Transactions on Power Delivery, Vol. 14, No.1, January 1999

Maciej Wenerski received the M.Sc. degree from the Technical University of Łódź (TUL) in 2009 after defending his thesis entitled: "Fuzzy logic simulator and library". He is a Ph.D. student of the Department of Microelectronics and Computer Science at TUL since September 2009.

Paweł Marcinak received the M.Sc. degree from the Technical University of Łódź (TUL) in 2009 after defending his thesis entitled: "The use of SCADA System in Visualization of Medicine Production Process". He is a Ph.D. student of the Department of Microelectronics and Computer Science at TUL since September 2009.

Radosław Tomala received the M.Sc. degree from the Technical University of Łódź (TUL) in 2009 after defending his thesis entitled: "Shape recognition algorithms in thermal imaging analysis". He is a Ph.D. student of the Department of Microelectronics and Computer Science at TUL since September 2009.

Rafał Kotas received the M.Sc. degree from the Technical University of Łódź (TUL) in 2009 after defending his thesis entitled: "Data Glove Controlled by Microprocessor System". He is a Ph.D. student of the Department of Microelectronics and Computer Science at TUL since September 2009.