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A Novel Approach for Leak Detection in Water Pipe Lines Using Artificial Intelligence Techniques

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ABSTRACT

A new method is presented for detecting and locating leakage in the water transmission pipes. In order to reduce the required time for leak detection and to reduce the water losses and enhance the overall process, the artificial intelligence technique is used. This research work aims at finding new approach to overcome all the disadvantages of the current means of detecting leakage. It is one considered of the most cost reducing method. The obtained results are promising. Leakage is one of the most frequent and serious problems that occur in water pipelines, as it causes wasting a considerable percentage of produced water. It also negatively affects the infrastructure, buildings and public health. Reducing leakage would maintain sustainable water supply to fulfill domestic and industrial demands and protect water pipelines from deterioration. Leak detection by the conventional means consumes a lot of time and resources. The proposed approach detects leakage points using Artificial Intelligence through making simulation by integration of an authorized analysis programs as follows: firstly, the water transmission pipes are analyzed using WaterCAD which is a hydraulic analysis program, Secondly the obtained results are simulated data using MATLAB program. Finally, through a Simulink diagram that obtained, the leakage location is accurately determined using only discharge value at line begins and pressure value at the line end.

Key words: Leak detection; Water Discharge; Pressure at Pipe Line; Artificial Intelligence; Water transmission pipes.

Introduction

According to continuous need to improve the water supply system and protecting it from deterioration that lead to poor operation and protect water quality against leakage that decreases water quality Also, to reduce the needed time to detect the location of leakage to reduce the loses in produced water .

Parameters affecting the volume of losses:

The volume of losses in water will depend on.

a) The pressure in the system.
b) The awareness time (the time taken from start of the leak and noticed by utility) and location time (time taken to locate the spots of leaks)
c) Type of soil which allow the water to be visible at the surface.
d) Repair time (how quickly the loss is repaired).
e) The frequency and typical flow rates of new leaks and bursts.
f) The proportions of new leaks which are reported.
g) The level of "background" leakage (undetectable small leaks). (Farley and Trow 2003; Gramel and Herz 2011)

Background of Water Leakage

It comes from weeps and seeps in the joint pipe. It is too small less than (250 l/hr), to be detected by Acoustic leak detection. It takes some time to know this type of losses and they reduce this loss by infrastructure replacement or pressure management and reduction the number of joints. This type of leakage considers the major part of real losses which cannot remove it in most cases Farley and Trow (2003).

Reasons of Leakage

There are several factor causes the leakage and increase the amount of it:

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*Pressur***e**

Pressure is very important factor on the leakage. The importance of management of excess pressure is very important to leakage management strategy. International data on pressure, leakage relationships demonstrate that leakage in distribution systems as well as in pipe lines is usually much more sensitive to pressure than predicted by square root relationships (Lambert, 2000).

Soil Movement and Characteristics

There are several factors effect on soil movement cause pipe break, joints move and pipe failure. These factors are:-

- Temperature change
- Subsidence like earthquake and mining
- Moisture change especially in clay which affect on cast iron pipes (Farewell *et al.,* 2011).

Pipe state

In most cities, older suburbs have a higher proportion of older pipe types and consequentially higher leakage, while plastic pipes with lower leakage will predominate in newer subdivisions. A similar pattern of leakage can be expected from pipe types in water distribution and reticulation networks as well as in pipelines as explained in. Dhammika *et al.,* (2009). Failure in cast iron study by National Research Council in Canada was found that there is several factors affecting on this type of pipe like in addition to corrosion, manufacturing defects, human error and unexpected levels of pipe loading. All of this factor plays a role in the large number of pipe failures that occur each year (Makar *et al.*, 2001).

Location of leakage

Leakage occurs in the following locations:

a) Main trunk and distribution system
b) From pipes, joints and valves. It is usually medium to high flow rate and short to medium runtime.
c) Service connection

The main objective of the knife valves is stopping the flow. During leak from the closed valves and this may cause financial losses, environment and personal risks. So regular tests must be done on valves to reduce the probability of leakage (Meland *et al.,* 2011).

It is refer to weak point of connection due to its high failure rates. It has low flow rate and difficult to detect. It has long runtime.

Study objectives

The objective of this study is to find a new approach to cover the gaps of all the disadvantage of the current means of detecting leakage. For example Correlator is one of these modern systems.

Operation theory of correlators

This device uses a sensor to measure on one appurtenants along the pipeline, and another sensor on the other side of the same pipeline. In the case of leakage, a sound wave is produced and spread through the pipe and another one spreads in the liquid (water). Figure (1-1) shows the correlators), as used in leakage department in Holding Company for Water and Wastewater.

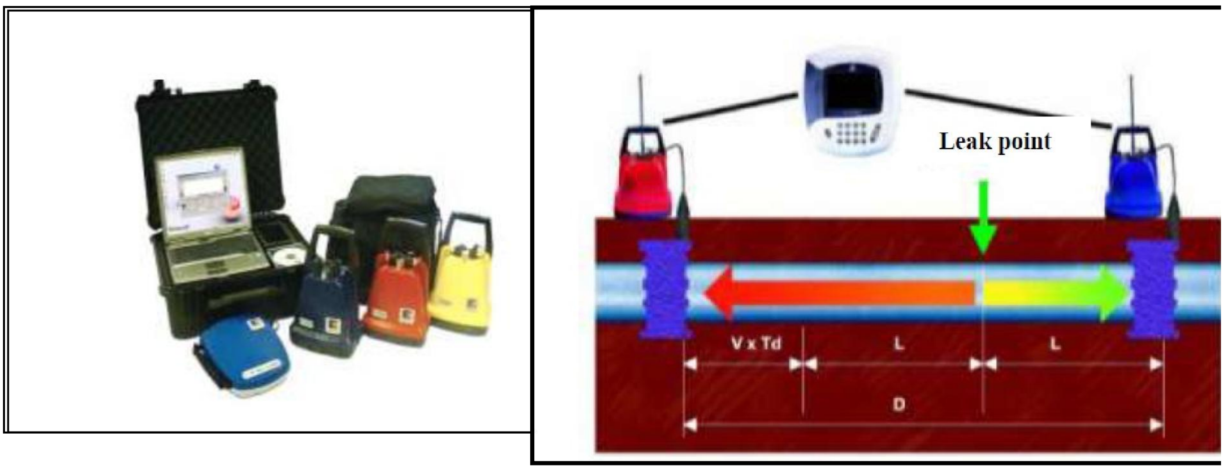

Fig. (1-1): Correlator, Sensors and Operation theory of Correlators

Work tested for 50 m by correlators to get check of leak in the water pipe line needs:
- 3 Technicians as man power.
- Time requisite to run 50 m about 15 minutes

So at testing for 3.249 Kilometer long this means we need (3249/50)*15 minutes = 16.24 hours to test for leakage. In comparison, this study proposed a new method for detecting location of a leak in water transmission pipes in shorter time and more efficiency. This proposed method is based on Artificial Intelligence (AI). AI methods are used in many applications as given in Bahgaat *et al.* (2001), and Ismail and Moustafa Hassan (2012).

Water line data

The simulated pipeline is 3.249 kilometer long. However, the actual pipeline is under construction in the district AbuZaabal Governerate Qaliuobia. The Diameter of the pipeline is 12". The material of the actual pipeline is High Density Polyethylene (HDPE). Furthermore, these data are considered in the simulation for the pipeline using WaterCAD program.

Methodology

Results obtained from WaterCAD will be presented for every scenario separately to get the different values of pressure and discharge for any point in the simulated pipeline. After that, the results will be utilized by Matlab program to make simulation and training using AI, then get the results from Simulink diagram. This diagram will be used to identify the positions of leaks and its percentage, consequently, to ensure the reliability of the process. Different points will be chosen on the water line that weren't analyzed hydraulically before. These points are identified only by its known locations and by different leak percentage. The obtained values are different from the former values used in running MatLab/Simulink diagram. These new values of pressures and discharge will be used to check the reliability of the proposed method.

Results of Water Cad Program

Different Points were chosen on the simulated transmission pipe as illustrated in Figure (1-2), at (J7 -J14 - J23 - J33 - J43 -J51 - J59 - J68).considering (J7 = joint7) Leakage will be assumed at many points on a transmission pipe with variable leak percentage starting from (2.5% , 5% ,10% - 15% , 20% , 30% , 40% , 50% , 60% 70% , 80%).

After running the hydraulic analysis, leak was simulated at points (J7 -J14 - J23 - J33 - J43 -J51 - J59 - J68) with leakage Percentage (2.5% - 5% - 10% - 15% - 20% - 30% - 40% - 50% - 60% 70% - 80%). Then the results were compiled for discharge at the beginning of the line and for the Pressure at the end of the line in the case of leak and no leak as illustrated in Table (1-1).

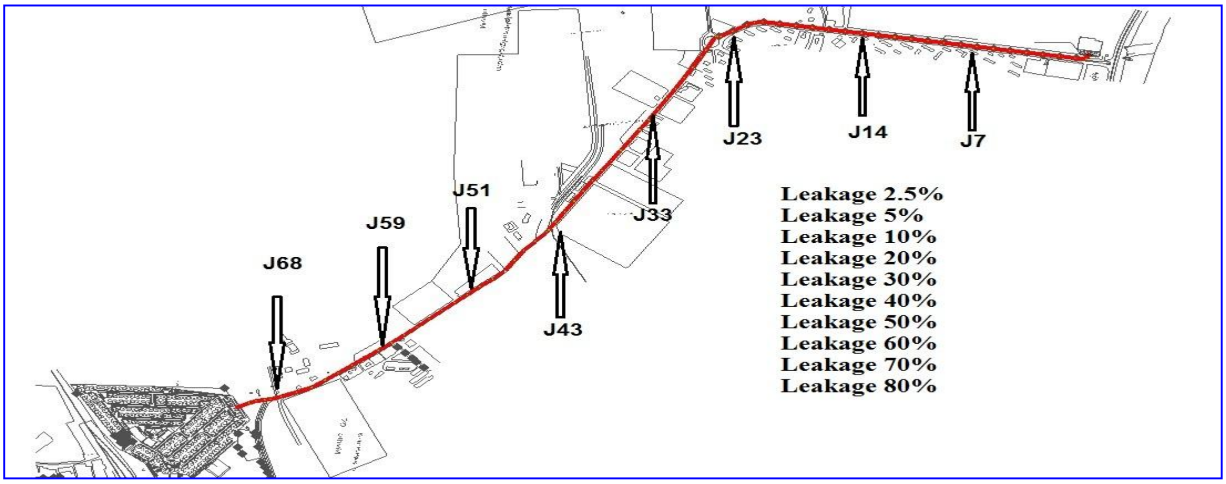

Figure (1-2): Schematic Diagram for the Simulated Pipeline

Detection of Water Leakage

In the tables (1-1) and (1-2) points between existence and non-existence of leakage will be utilized in the program while 0 indicates non leakage point and 1 represent the occurrence of leakage in different locations.

The used results that will be inserted in ANFIS includes discharge (Q) at beginning the pipe line & Pressure (P) at the end pipe line and then Index of Leakage (0 & 1) after that membership function will be selected and then adjusting type to linear and finally run on MATLAB programs. The detection is done via ANFS considering zero distance as no leak. While any different reading will indicate leak at the given distance.

Locating the Leak

The compiled results for discharge at the beginning of the line and Pressure at the end of the line were utilized by MatLab program to make a simulation for the leak at different distances. It is assumed that leakage at Joint 7 that is located at a distance 0.312 km and Joint 14 that is located at a distance 0.662 km, Joint 23 that is located at a distance 1.026 km, Joint 33 that is located at a distance 1.412 km, Joint 43 that is located at a distance 1.911 km, Joint 51 that is located at a distance 2.260 km, Joint 59 that is located at a distance 2.660 km, Joint 68 that is .located at a distance 3.011 km. the above data are presented at Tables (1-1) and (1-2).

The Concept of ANFIS

The acronym ANFIS derives its name from Adaptive Neuron Fuzzy Inference System. Using a given input/output data set, the toolbox function *"anfisedit"* constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a backpropagation algorithm alone or in combination with a least squares type method. This adjustment allows the fuzzy systems to learn from the data they are modeling (Bahgaat *et al.,* 2001 and Ismail and Moustafa Hassan, 2012).

Table (1-1): Compiled Results for Discharge and Pressure at 2.5% Leak at Different Joints

Discharge (Q)at J- 1	Hydraulic Grade (m) at J-74	Index of Leakage	Distance (km)	Leakage Joint
92.59	35.87	0	0	No Leakage
94.89	35.25	1	0.312	Leakage at Joint 7 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	35.18	1	0.662	Leakage at Joint 14 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	35.09	1	1.026	Leakage at Joint 23 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	35.02	1	1.412	Leakage at Joint 33 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	34.92	1	1.911	Leakage at Joint 43 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	34.84	1	2.26	Leakage at Joint 51 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	34.76	1	2.66	Leakage at Joint 59 =2.3 L/S (2.5%)
92.59	35.87	0	0	No Leakage
94.89	34.67	1	3.11	Leakage at Joint 68 =2.3 L/S (2.5%)

Table (1-2): Compiled Results for Discharge and Pressure at 5% Leak at Different Joints

Discharge (Q)at J- 1	Hydraulic Grade (m) at J-74	Index of Leakage	Distance km	Leakage Joint
92.59	35.87	0	0	No Leakage
97.19	34.62	1	0.312	Leakage at Joint 7 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	34.47	1	0.662	Leakage at Joint 14 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	34.3	1	1.026	Leakage at Joint 23 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	34.15	1	1.412	Leakage at Joint 33 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	33.94	1	1.911	Leakage at Joint 43 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	33.79	1	2.26	Leakage at Joint 51 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	33.63	1	2.66	Leakage at Joint 59 =4.6 L/S (5%)
92.59	35.87	0	0	No Leakage
97.19	33.44	1	3.11	Leakage at Joint 68 =4.6 L/S (5%)

Practical Work on MatLab

The work on MatLab could be listed as follow**.**

a) Insert all results in ANFIS GUI using command "*anfisedit*"

a) Select membership functions (MF) (gaussmf, trimf, trapmf, ……..etc)
b) Adjust type to (linear, constant)
c) Run on MatLab (Training of the Data)
The average testing error equal 0.01529, which is acceptable (as shown in Figure (1-3)).

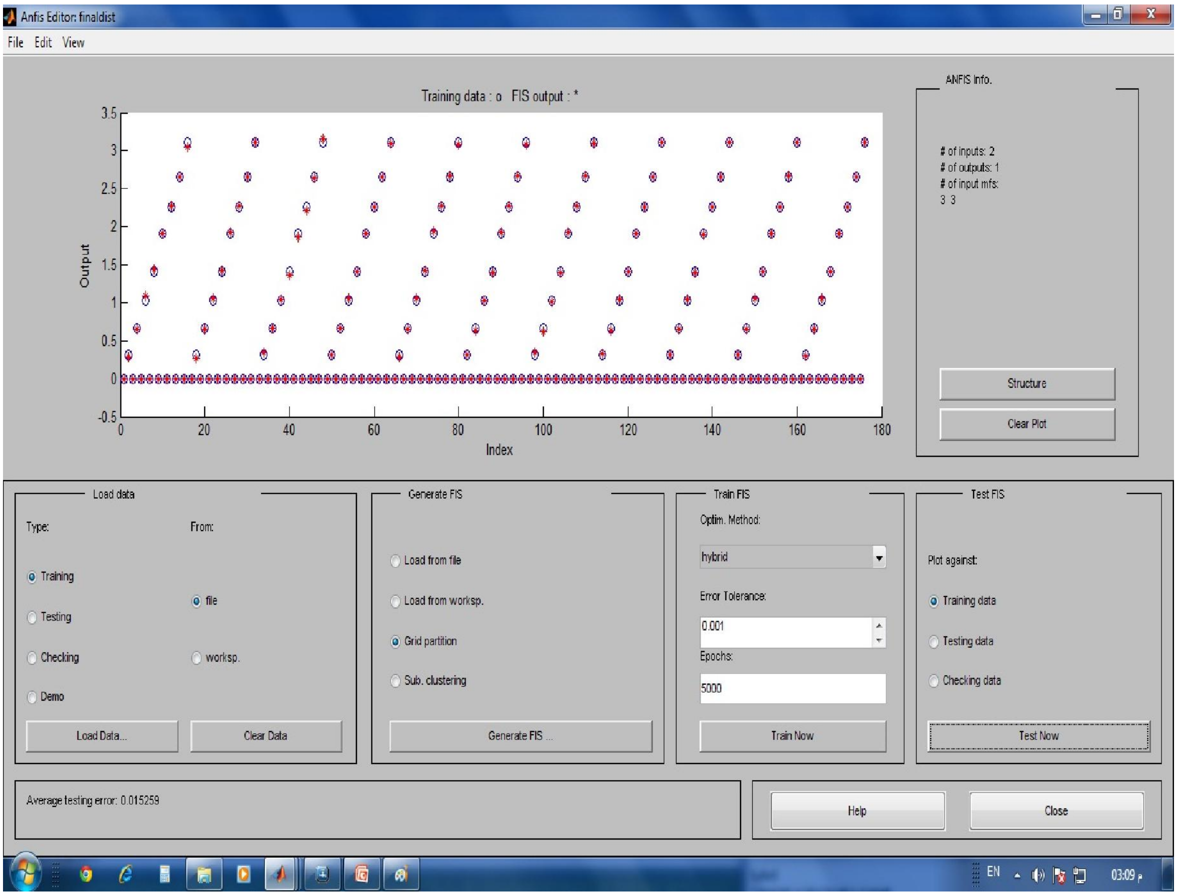

Fig. (1-3): Matching results which means the least error

The results are exported to be used in a program for Fuzzy Logic Controller (FLC) to be ready to determine the leakage distance at different pressure and flow values. This is represented in the shown Simulink diagram, as illustrated in Figure (1-4).

Simulation Leak at Different Joints with different percentage of Leakage

To get the leak point, another test will be made using different Joints (J10 -J19 - J28 - J37 - J48 -J56 - J63) with variable leak percentage (0.5% - 1.5% -3.5% - 7% - 15% - 25% - 35% - 45% 55% - 65% - 90%), as given in Table (1-3) and Table (1-4) . These values are not used in the previous training.

Determination of the Distance of Leak could be determined as follow:

The Determination of the Distance of Leak could be given as:
a) Assume leakage at distance 462 m (Joint 10 (J10)) with percentage Leak 3.5%
b) Analyze with WaterCAD program to get the discharge at the beginning of the line and the pressure at the end.
It was found that: Flow = 95.83 (l/s) and Hydraulic Grade = 34.95 m.
c) Enter this data in Simulink diagram for obtaining the distance of leak. The obtained results as illustrated in Figure (1-5) and table (1-3).

However, this information were not used in the training process based on ANFISThe leak distance = 447m showing that the percentage error = ((447-462)/462)*100 =3.25 % which is an acceptable accuracy, as illustrated in Figure (1-5).

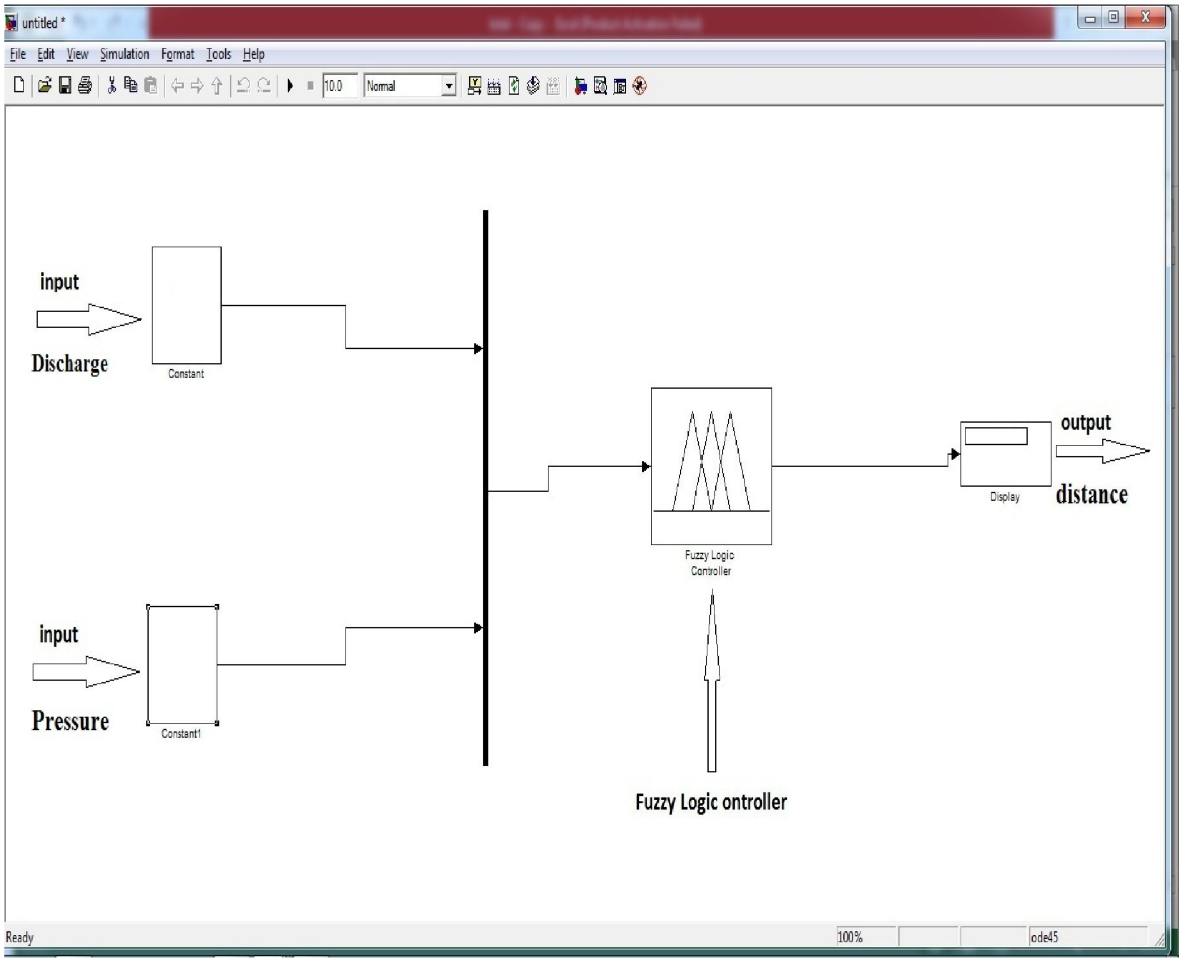

Fig. (1-4): Simulink diagram

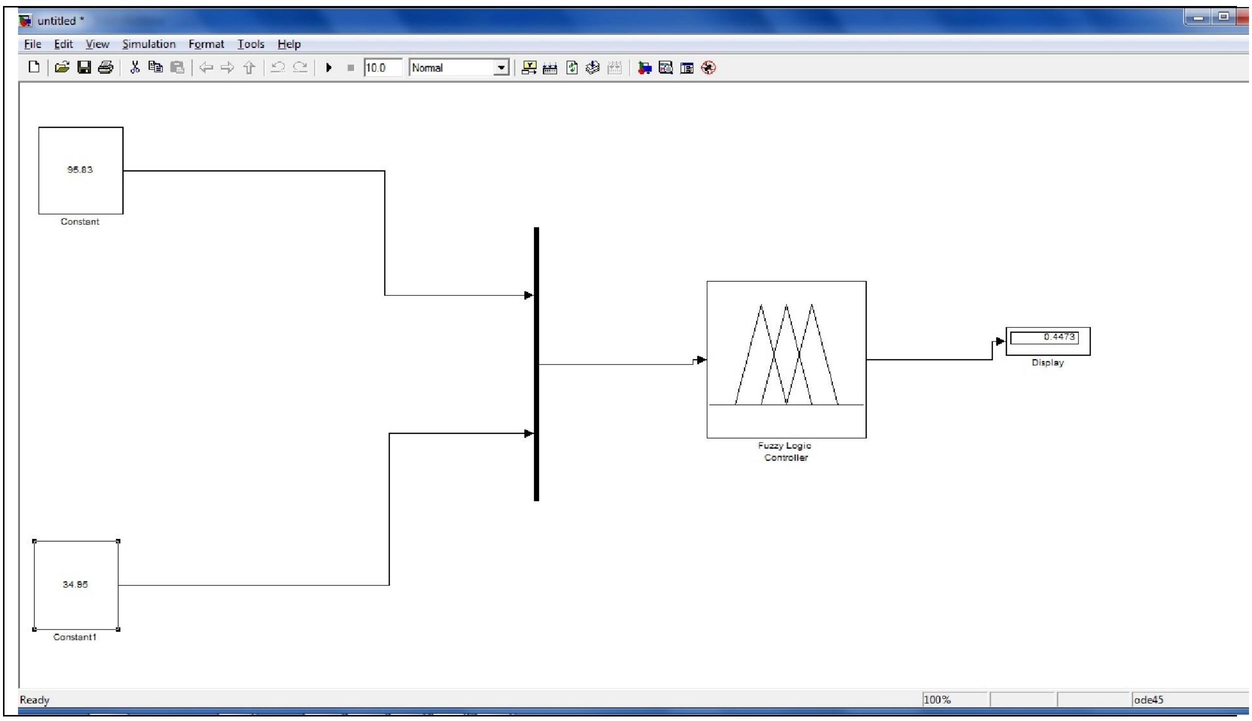

Fig. (1-5): Simulink diagram for Leakage at Joint 10 = 3.24 L/S 3.5%

Table (1-3): Compiled test Results at Different Joints with constant leak percentage 3.5%

Flow (L/s)	Hydraulic Grade (m)	Actual distance (m)	Test distance (m)	Error Absolute Percentage %	Leakage point
95.83	34.95	462	447.3	3.18	Leakage at Joint 10 = 3.24 L/S (3.5%)
95.83	34.82	912	929.8	1.95	Leakage at Joint 19 = 3.24 L/S (3.5%)
95.83	34.73	1213	1256	3.54	Leakage at Joint 28 = 3.24 L/S (3.5%)
95.83	34.61	1611	1683	4.47	Leakage at Joint 37 = 3.24 L/S (3.5%)
95.83	34.46	2110	2205	4.50	Leakage at Joint 48 = 3.24 L/S (3.5%)
95.83	34.34	2510	2614	4.14	Leakage at Joint 56 = 3.24 L/S (3.5%)
95.83	34.24	2860	2951	3.18	Leakage at Joint 63 = 3.24 L/S (3.5%)

Table (1-4): Compiled test Results at Different Joints with constant leak percentage 7%

Flow (L/s)	Hydraulic Grade (m)	Actual distance (m)	Test distance (m)	Error Absolute Percentage %	Leakage point
99.07	34	462	446	3.46	Leakage at Joint 10 = 6.48 L/S (7%)
99.07	33.73	912	867	4.93	Leakage at Joint 19 =6.48 L/S (7%)
99.07	33.55	1213	1151	5.11	Leakage at Joint 28 = 6.48 L/S (7%)
99.07	33.31	1611	1534	4.78	Leakage at Joint 37 = 6.48 L/S (7%)
99.07	33.01	2110	2028	3.89	Leakage at Joint 48 = 6.48 L/S (7%)
99.07	32.77	2510	2439	2.83	Leakage at Joint 56 = 6.48 L/S (7%)
99.07	32.56	2860	2812	1.68	Leakage at Joint 63 = 6.48 L/S (7%)

Discussion

Case 1: Results Greater Than 2.5 % leakage:
Checking Using the Trained in "Anfisedit"

Hydraulic analysis and leaks simulation work are assumed before at the following points (J7 -J14 - J23 - J33 - J43 -J51 - J59 - J68) at leakage Percentage (2.5% - 5% -15% - 10% - 20% - 30% - 40% - 50% - 60% 70% - 80%). Now, a test will be done to determine the leak point. When entering the value of discharge at beginning line and pressure at the end line in Simulink diagram leak point will be obtained.

Checking using data not used in the training

To get the leak point, another test will be don using different points (J10 -J19 - J28 - J37 - J48 -J56 - J63) with variable leak percentage (0.5% - 1.5% -3.5% - 7% - 15% - 25% - 35% - 45% 55% - 65% - 90%)

In case (1)

a) 88 tests were made for the points at different percentages and trained using *Anfisedit*.
b) 69 tests were made for different points not used for training on Matlab. at different percentage leak.

It was found that 142 readings (among 157 reading) are less than 5% error while 11 readings are greater than 5% error, and less than 10 % error while 4 readings are greater than 10% error and less than 13.64% error.

Case 2: results less than 2.5 %leakage:
Checking using the trained in "Anfisedit"

Hydraulic analysis and leaks simulation work are assumed before at the following points (J7 -J14 - J23 - J33 - J43 -J51 - J59 - J68) at leakage Percentage (0.5% - 1% -1.5% - 2% - 2.5%). now, we will test to determine the leak point.

Checking using data not used in the training

To get the leak point, we will make another test using different points (J10 -J19 - J28 - J37 - J48 -J56 - J63) with leak percentage (0.5% - 1.5%). And Random selection for leak percentage and location.

In case (2)

a) 40 tests were made for the points at different percentages and trained using Anfisedit.
b) 20 tests were made for different points not used for training on Matlab. at different percentage leak.

It was found that 50 readings (among 60 reading) are less than 5% error while 6 readings are greater than 5% error, and less than 20 % error while 4 readings are greater than 10% error and less than 12.7% error.

Conclusions

This research work aims to detection determine the location of leakage in water transmission pipes using hydraulic analysis using WaterCad program and Matlab program . The obtained results from WaterCad will be utilized by Matlab program to make simulation and training and then get find results from Simulink diagram. This diagram will be used to identify the positions of leaks and its percentage, consequently, to ensure the reliability of the process. Different points were chosen on the water line that weren't trained before. These points are identified only by its known locations and by different leak percentage. The obtained values are different from the former values used in running MatLab/Simulink diagram. These new values of pressures and discharge will be used to check the reliability of the proposed method. The proposed technique is based on one of famous Artificial Intelligence, which is ANFIS. The obtained results are promising and reliable as well as based on minimum number of instrumentation. The required instrumentation are: the discharge at the beginning of the line and the pressure at the end of the line.

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