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A New Approach for Leak Detection IN Transmission water pipelines Using Artificial Intelligence

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Abstract— Leakage is one of the most frequent and serious problems that occurs in water pipelines, as it causes wasting a considerable percentage of produced water. It also negatively affects the infrastructure, buildings and the 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.

This research presents a new method for detecting and locating leakage in the water carrier pipelines, in order to reduce the required time for leak detection and to reduce the water losses and enhance the overall process. This dissertation aims at finding a new approach to overcome all the disadvantages of the current means of detecting leakage. It is considered one of the most cost reducing methods.

This approach detects leakage points using artificial intelligence through making simulation and training by integration of an authorized analysis programs. Firstly, the water carrier pipelines are analyzed using Water-CAD which is a hydraulic analysis program. Secondly, the obtained results data are simulated using MATLAB program. The training is based on Neuro Fuzzy approach called Adaptive Neuro Fuzzy Inference Systems (ANFIS) which is well known among the artificial intelligence techniques.

Finally, through a Simulink diagram, the leakage location is accurately determined using change in discharge and pressure values in the water carrier pipelines.

Index Terms— Leak detection, Water Discharge, Pressure at Pipe Line, Artificial Intelligence, water lewakage, discharge, pressure.

1 Introduction

Water supply system is a necessary service for all communities. Water and air are the main life components. Fresh water is not vital only for human but it is also used for industrial and agriculture purposes. The water resources are limited. However, the population increases leading to an increase in the need of fresh water. The World information Bank reports that over one billion people in the world today lack to safe drinking water and three million people die yearly due to water-related diseases E. M. F. Abd El-kader (2014)

1.1 Parameters Affecting The volume of losses:

The volume of losses in water depends on.

a) The pressure in the system.

b) The awareness time (the time taken from the start of the leakage and noticed by utility) and location time (time taken to locate the spots of leakage)

c) Type of soil which allows 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 leakages). Farley and Trow (2003) & Gramel and Herz (2011)

1.2 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 then reduces this loss by infrastructure replacement or pressure management and reduction of the number of joints. This type of leakage considers the major part of real losses which cannot be removed in most of cases Farley and Trow (2003).

1.3 Reasons of Leakage

There are several factors that cause the leakage and increase its amount:

1.31 Pressure

Pressure is a very important factor of 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. A (2000)

1.32 Soil Movement and Characteristics

There are several factors whose effects 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 affects cast iron pipes Timothy, et al (2011).

1.33 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 De Silva. Dhzammika et al (2009). Failure in cast iron is studied by National Research Council in Canada and it was found that there are several factors affecting this type of pipes in addition to corrosion, manufacturing defects, human error and unexpected levels of pipe loading. All of these factors play a role in the large number of pipe failures that occur each year J. M. Makar et al (2001).

1.4 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 to stop 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. E. Meland, et al (2011).

It is referred to weak point of connection due to its high failure rates. It has low flow rate and difficult to detect. It has long runtime. **Thornton, et al** (2008).

1.5 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.

2. Operation Theory of Correlators

This device uses a sensor to measure 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 spreads 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.

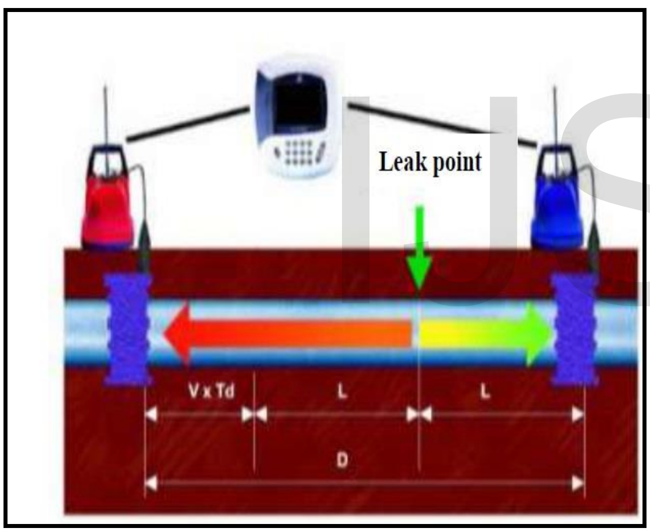


Figure (1-1) Correlator, Sensors and Operation theory of Correlators

Work is 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, when 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 the location of leak in water transmission pipes in shorter time and more efficiently. This proposed method is based on Artificial Intelligence (AI). AI methods are used in many applications as given in N.K. Bahgaat et al (2001). And Ismail, M. A. Moustafa (2012).

3. 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. N.K. Bahgaat et al (2001). And Ismail, M. A. Moustafa (2012).

4. Water line data

The simulated pipeline is 3.249 kilometer long. However, the actual pipeline is under construction in the district AbuZaabal, Qaliuobia Governerate. 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.

5. Methodology

Results obtained from Water CAD 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.

this Paper discusses two of the most common cases in transmitting and supplying water by Analyzing and studying leakage theory, these cases are stated as follows: First case: Supplying the demand by a Transmission pipeline directly connected to a tank with an acting single-speed pump. Second case: Supplying the demand by a Transmission pipeline directly connected to a network with acting variable-speed pump. This method could be applied to wastewater force mains.

6. Case study

Supplying the demand by a transmission pipeline directly connected to a tank using single-speed pump

7. Results of Water Cad Program

Different Points will be chosen on the simulated carrier pipeline at (J5 -J10 – J15 – J20 – J25 –J30 – J35 – J40- J45 –J50 – J55 – J60 – J65 – J70– J73). Leakage will be assumed at many points on a carrier pipeline with variable leak percentage starting from (5% -10% - 15% - 20% - 25% - 30% - 35% - 40% - 45% - 50%). Figure (1-2)

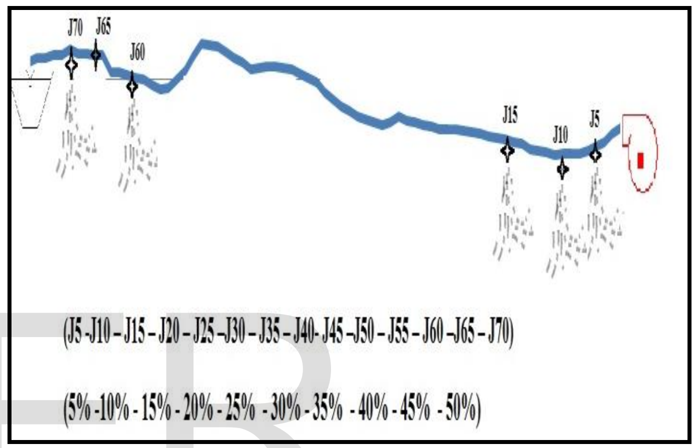


Figure (1-2): Different Points Chosen on the Simulated Carrier Pipeline

8. Hydraulic Grade line Diagram

Hydraulic Grade line Diagram for different percentage leak at the same joint is represented in Figures (1-3).

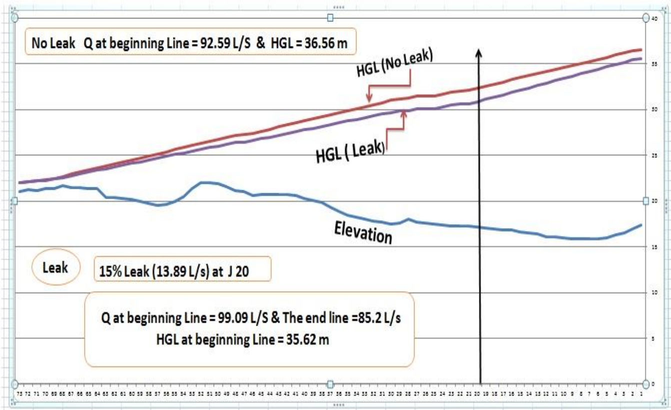


Figure (1-3): Hydraulic Grade line Diagram at 15% leak and no leak at joint 20

9. 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 results inserted in ANFIS include: discharge (Q) at beginning the pipe line, end line & Hydraulic Grade (HGL) at the beginning pipe line. And then Index of Leakage (0 & 1). After that membership function will be selected and adjusted 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.

Table (1-1) Compiled Results for Discharge and Hydraulic pressure at Different percentage Leak at Joint 5

Dis-charge(Q)at J- 1	Dis-charge (Q)at J-73	Hydrau-lic pres-sure (m) at J-1	Dis-tance km	Index Leak-age	**Leakage Joint**
92.59	92.59	36.56	0	0	No Leakage
95.53	90.9	36.15	0.201	1	5 % Leak (4.63 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
98.4	89.17	35.73	0.201	1	10 % Leak (9.23 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
101.26	87.37	35.3	0.201	1	15 % Leak (13.89 L/s) at J 5
92.59	92.59	36.56	0	0	No Leakage
104.05	85.53	34.87	0.201	1	20 % Leak (18.52 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
107	83.49	34.4	0.201	1	25 % Leak (23.51 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
109.48	81.7	33.99	0.204	1	30 % Leak (27.78 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
112.12	79.72	33.55	0.201	1	35 % Leak (32.4 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
114.71	77.67	33.11	0.201	1	40 % Leak (37.04 L/s) at J5

92.59	92.59	36.56	0	0	No Leakage
117.25	75.58	32.67	0.201	1	45 % Leak (41.67 L/s) at J5
92.59	92.59	36.56	0	0	No Leakage
119.73	73.44	32.22	0.201	1	50 % Leak (46.29 L/s) at J5

10. Locating the Leak

The compiled results for discharge at the beginning line, end line and Hydraulic Grade, at the beginning line, and the results will be utilized by MATLAB program to make a simulation for the distance. This paper assumes that the leakage at joints 5,10,20,25,30,35,40 and 45 are located at distances 0.201,0.451, 0.951, 1.143, 1.251, 1.501, 1.745 and 2 km respectively.

Table (1-2) Compiled Results for Discharge and Hydraulic Grade at Different percentages of Leak at Joint

Discharge(Q)at J-1	Discharge (Q)at J-73	Hydraulic Grade (m) at J-1	Distance km	Index Leakage	Leakage Joint
92.59	92.59	36.56	0	0	No Leakage
95.29	90.66	36.18	0.451	1	5 % Leak (4.63 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
97.92	88.69	35.8	0.451	1	10 % Leak (9.23 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
100.53	86.64	35.41	0.451	1	15 % Leak (13.89 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
103.08	84.56	35.02	0.451	1	20 % Leak (18.52 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
105.57	82.42	34.63	0.451	1	25 % Leak (23.51 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
108.01	80.23	34.23	0.451	1	30 % Leak (27.78 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
110.4	77.99	33.84	0.451	1	35 % Leak (32.4 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
112.74	75.7	33.45	0.451	1	40 % Leak (37.04 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
115.02	73.35	33.06	0.451	1	45 % Leak (41.67 L/s) at J10
92.59	92.59	36.56	0	0	No Leakage
117.24	70.95	32.67	0.451	1	50 % Leak (46.29 L/s) at J10

11. Practical Work on MATLAB

The work on MATLAB could be listed as follows.

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 obtained average testing error equals 0.0064601, which is good, as shown in Figures (1-4):(1-6).

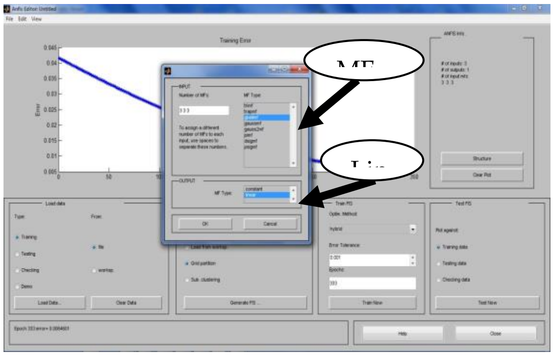


Figure (1-4): Selection of Membership Functions (MF) gbellmf and the Linear

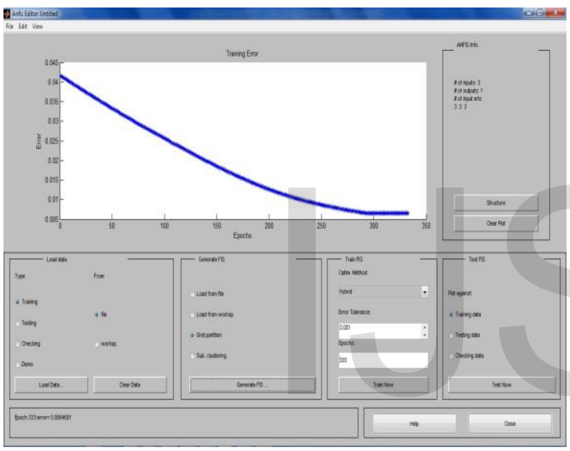


Figure (1-5): Running Error of ANFIS on MATLAB Program

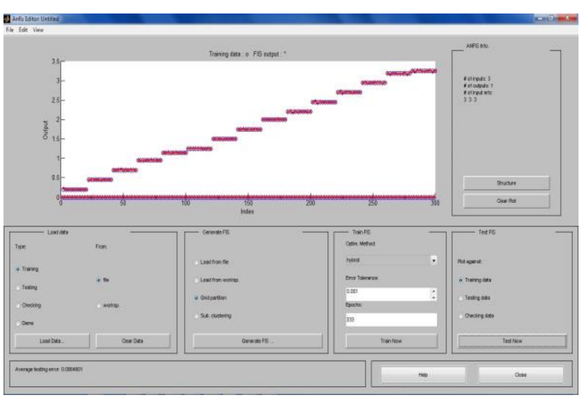


Figure (1-6): Matching Results Which Means the Least Error

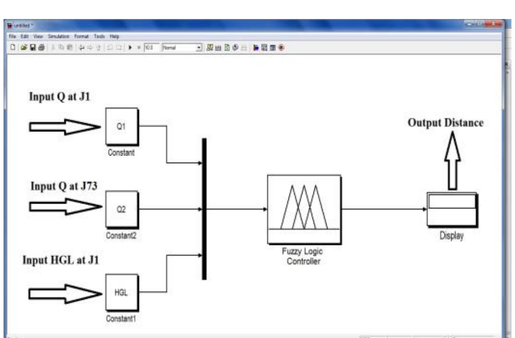


Figure (1-7): Simulink Diagram

the results are used to program a fuzzy logic controller in Simulink environment to be ready to determine the leakage distance at different discharges at the beginning line, end line and Hydraulic Grade at the beginning line.

This is represented in the shown Simulink diagram as given in Figure (1-7)

12. Determining the Leakage Point

Different cases will be discussed:

12.1 CHECKING USING THE TRAINED DATA IN "ANFISEDIT"

Hydraulic analysis and leaks simulation work are assumed before at the following points (J5 -J10 – J15 – J20 – J25 –J30 – J35 – J40- J45 –J50 – J55 - J60 –J65 – J70 – J73). at leakage Percentage (5% -10% - 15% - 20% - 25% - 30% - 35% - 40% - 45% - 50%). now, we will test to determine the leak point.

The obtained results are listed in Tables (1-3),(1-4).

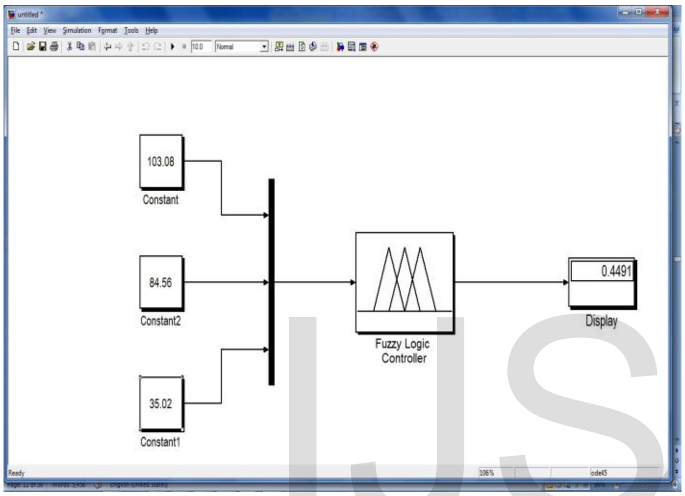
Discharge (Q)at J- 1	Discharge (Q)at J-73	Hydraulic pressure Grad (m)at J-1	Actual Distance (m)	Test Distance (Km)	Absolute Percentage Error %	Leakage Joint
95.29	90.66	36.18	0.451	0.437	3.10	5 % Leak (4.63 L/s) at J10
97.92	88.69	35.8	0.451	0.453	0.44	10 % Leak (9.23 L/s) at J10
100.53	86.64	35.41	0.451	0.453	0.44	15 % Leak (13.89 L/s) at J10
103.06	84.56	35.02	0.451	0.449	0.44	20 % Leak (18.52 L/s) at J10
105.57	82.42	34.63	0.451	0.451	0.67	25 % Leak (23.51 L/s) at J10
108.01	80.23	34.23	0.451	0.447	0.89	30 % Leak (27.78 L/s) at J10
110.4	77.99	33.84	0.451	0.451	0.67	35 % Leak (32.4 L/s) at J10
112.74	75.7	33.45	0.451	0.448	0.67	40 % Leak (37.04 L/s) at J10
115.65	73.35	33.06	0.451	0.451	0.00	45 % Leak (41.67 L/s) at J10
117.23	70.95	32.67	0.451	0.453	0.44	50 % Leak (46.29 L/s) at J10

Discharge (Q)at J- 1	Discharge (Q)at J-73	Hydraulic pressure Grad (m)at J-1	Actual Distance (m)	Test Distance (Km)	Absolute Percentage Error %	Leakage Joint
95.53	90.9	36.15	0.201	0.219	8.96	5 % Leak (4.63 L/s) at J5
98.43	89.17	35.73	0.201	0.198	1.49	10 % Leak (9.23 L/s) at J5
101.28	87.37	35.3	0.201	0.194	3.48	15 % Leak (13.89 L/s) at J 5
104.05	85.53	34.87	0.201	0.201	0.20	20 % Leak (18.52 L/s) at J5
107	83.49	34.4	0.201	0.202	0.50	25 % Leak (23.51 L/s) at J5
109.48	81.7	33.99	0.201	0.207	1.47	30 % Leak (27.78 L/s) at J5
112.12	79.72	33.55	0.201	0.198	1.49	35 % Leak (32.4 L/s) at J5
114.71	77.67	33.11	0.201	0.204	1.49	40 % Leak (37.04 L/s) at J5
117.22	75.58	32.67	0.201	0.197	0.65	45 % Leak (41.67 L/s) at J5
119.74	73.44	32.22	0.201	0.207	0.15	50 % Leak (46.29 L/s) at J5

Table (1-3) Compiled Test Results Different Percentage leak at joint 5

Table (1-4) Compiled Test Results Different Percentage leak at joint 10

When entering the value of discharge at the beginning line, end line and Hydraulic



Pressure at the beginning line. We get leak point, as shown in Figure(1-8)

Figure (1-8): Simulink Diagram for Leakage at Joint 10 = 18.52 L/S (20%)

13 Assuming leak at Different joints and different percentage

This part is done on data not used in the Training. To get the leak point, another test will be made using different joints with different variable leak percentage as illustrated in Figure (1-9).

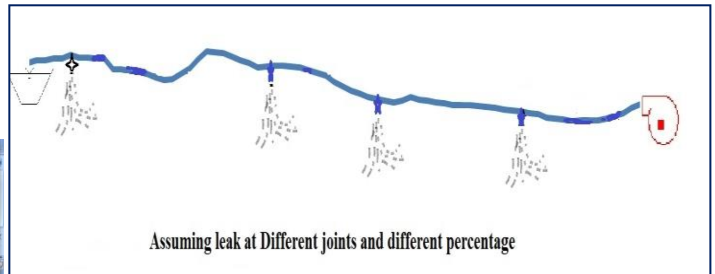


Figure (1-9): Schematic Diagram for the Tested Pipeline

- Check Number One:
- ssume leakage at distance 601 m (joint 13 (J13)) with percentage 25%
- nalyze at Water CAD program to get the discharge at the beginning line, end line and Hydraulic Grade at the beginning line.
- t was found that: Flow (l/s) at J1 = 105.02 and Flow (l/s) at J1 = 81.51 Hydraulic Grade = 34.71m
- nter this data in Simulink diagram as illustrated in Figure (1-10)

▪

et: the leak distance = 587 m shows that the percentage

Discharge (Q)at J- 1	Discharge (Q)at J-73	Hydraulic pressure (m)at J-1	Actual Distance (m)	Test Distance (Km)	Absolute Percentage Error %	Leakage Joint
96.49	90.01	36.01	0.351	0.414	17.95	7 % Leak (6.48 L/s) at J8
99.21	88.1	35.61	0.351	0.32	8.83	12 % Leak (11.11 L/s) at J8
102.41	85.75	35.12	0.351	0.347	1.14	18 % Leak (16.66 L/s) at J8
104.5	84.14	34.79	0.351	0.33	5.98	22 % Leak (20.36 L/s) at J8
107.58	81.66	34.3	0.351	0.344	1.99	28 % Leak (25.92 L/s) at J8
110.09	79.54	33.89	0.351	0.36	2.56	33 % Leak (30.55 L/s) at J8
112.55	77.37	33.48	0.351	0.345	1.71	38 % Leak (35.18 L/s) at J8
114.95	75.14	33.07	0.351	0.353	0.57	43 % Leak (39.81 L/s) at J8
116.83	73.33	32.74	0.351	0.353	0.57	47 % Leak (43.5 L/s) at J8

error = ((601-587)/601) *100 =2.33 %

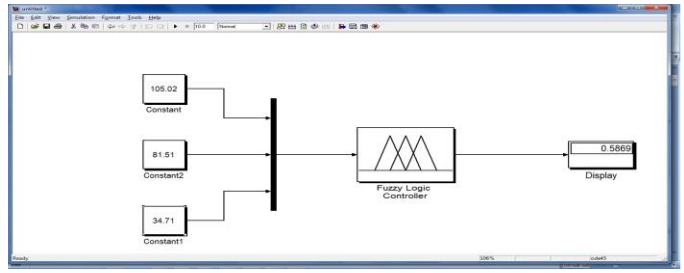


Figure (1-10): Simulink Diagram for Leakage at Joint 10 = 3.24 L/S 3.5%

Table (1-5) Compiled Test Results at Different Joints and Leakage

14. Dissection of the results for Leakage Greater than 5%

a) 150 tests were made for the points at different percentages and trained using anfisedit.

b) 256 tests were made for different points not used for training on MATLAB at different percentage leak.

It was found that 1 reading has 17.95 % error, 14 readings have error with percentage greater than 5% and less than 10 %, while 375 readings (among 406 reading) have error percentage less than 2%, and 391 readings (among 406 reading) have error percentage less than 5%

15. Conclusions

This research work aims to determine the location of leakage in water transmission pipes using hydraulic analysis using Water CAD program and MATLAB program. The obtained results from Water CAD will be utilized by MATLAB program to make simulations and trainings and then get results from Simulink diagram. This diagram will be used to identify the positions of leaks and their percentages, 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 their known locations and different leak percentages. The obtained values are different from the former values used in running MATLAB/Simulink diagram. These new values of pressures and discharges will be used to check the reliability of the proposed method. The proposed technique is based on one of the famous Artificial Intelligence programs, which is ANFIS. The obtained results are promising and reliable as well as based on minimum number of instrumentations. The required instrumentations are: the discharge at the beginning of the line and the pressure at the end of the line.

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