Cairo University

LEAKAGE DETECTION IN WATER PIPE NETWORKS USING ARTIFICIAL NEURAL NETWORKS TECHNIQUE

By

Eng: Mahmoud Mohamed Abdallah El-Hadidy

A Thesis Submitted to

The Faculty of Engineering at Cairo University

In Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

In

IRRIGATION AND HYDRAULICS ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

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Title of Thesis:LEAKAGE DETECTION IN WATER PIPE NETWORKS USING ARTIFICIAL NEURAL NETWORKS TECHNIQUE

Key Words: water leakage; water pipe networks; ANN; placement of pressure sensors

Summary:

National water security in Egypt is increasingly threatened by Upper Nile projects, climate-induced impacts, and mismanagement/misuse of the available resources. Leakage from pipe distribution networks may reach alarming values. At situations where every drop counts, it becomes inevitable to arrive at a leakage prediction and early warning system. In this study, a computational approach is followed to detect leakages in water distribution networks using Artificial Neural Networks (ANNs) technique. A multi-layer feed-forward back-propagation artificial neural network using Matlab Neural Network Toolkit is applied. The main objective of this research is to formulate a simple, yet effective leakage detection system (or more) appropriate for water supply networks. Secondary objectives include testing an applicable leakage detection system for Ismailia Water Distribution System (IWDS) to enhance its performance. Also, sensitivity analysis for such networks is applied to choose minimum number of sensors that can perfectly simulate leakage location and discharge in the studied networks. This study presents a generic methodology appropriate for leak detection both in location and magnitude.

A hydraulic model is created for the IWDS and about 1171 leakage scenarios at probable leakage nodes with different discharge ratios (20%, 30%, and 40% of maximum discharge passing through these nodes) are proposed to train ANN to recognize probable leakage locations and discharges corresponding to a wide range of sensor responses (ΔPs). Another 99 leakage scenarios with different discharge ratios (25%, 35%, and 45 % of maximum discharge passing through nodes) are proposed to calibrate the ANN model with post regression test. It's concluded that the ANN model presents a good and reliable alternative for simulating leakage detection for water supply networks. Finally, the study shows that leakage locations detected by the current methodology in 82 % of the cases tested lay within 600m or less from the actual coordinates and about 73% of the cases tested lay within 500m or less.

Acknowledgement

All thanks are for ALLAH the most merciful, the most beneficent for all his bounties.

I would like to express my deepest gratitude and appreciation to **Dr. Ahmed Wagdy**, Professor of Hydrology, Cairo University, for his sincere supervision, guidance, extremely helpful discussions, comprehensive review, valuable suggestions, and advice throughout the course of this work.

I am also deeply grateful for the valuable guidance of **Dr. Mohamed Gad El-rab**, Assistant Professor of Hydraulic and Irrigation, Cairo University for his time, dedication, patient, support, advice, participation, and guidance. He spared no effort or time in helping me to complete this work.

I wish express my deepest thanks to the Examining Committee **Amgad El-ansary**, Professor of Hydraulic and Irrigation, Cairo University, and. **Aly El-Bahrawy**, Professor of Hydraulic and Irrigation, Ain Shams University for their comprehensive advice, and comments that refine this work. I deeply appreciate their helpful response.

My gratitude also extends to the all these people who helped me in the production of this work especially, my friends **Dr. Mostafa Adel**, and **Eng. Mohamed El-Serafy**.

Finally, but no means least, I would like to thank my family (**Mother, wife**) without whom this work would not have been finished. Their endless patience and encouragement is a blessing.

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AC	Asbestos Cement
ANN	Artificial Neural Network
AWWA	American Water Work Association
DI	Ductile Iron
DMA	District Metering Area
FCV	Flow Control Valve
FFNN	Feed forward neural network
GPV	General Purpose Valve
IWA	International Water Association
IWPN	Ismailia Water Pipe Network
IWTP	Ismailia Water Treatment Plant
PBV	Pressure Breaker Valve
PRV	Pressure Reducing Valve
PSV	Pressure Sustaining Valve
SCA	Suez Canal Authority
TCV	Throttle Control Valve
UPVC	Unplasticized Polyvinyl Chloride
WPS	Water Distribution System
WTP	Water Treatment Plant
ΔP	Pressure difference (sensor response)

ABSTRACT

Leakage Detection in Water Pipe Networks Using Artificial Neural Networks Technique

National water security in Egypt is increasingly threatened by Upper Nile projects, climate-induced impacts, and mismanagement/misuse of the available resources. Leakage from pipe distribution networks may reach alarming values (nearly one third of the produced water is vulnerable to losses through undetected leakage). At situations where every drop counts, it becomes inevitable to arrive at a leakage prediction and early warning system. In earlier attempts, the literature for leakage detection location and discharge acknowledge high levels of uncertainties, and most of them do not incorporate the uncertainties related to the different water distribution system parameters in their algorithms. In this study, a computational approach is followed to detect leakages in water distribution networks using Artificial Neural Networks (ANNs) technique. ANNs are robust and can be used to model complex linear and non-linear systems without making implicit assumptions as is the case in most traditional statistical approaches. A multi-layer feed-forward back-propagation artificial neural network using Matlab Neural Network Toolkit is applied. The main objective of this research is to formulate a simple, yet effective leakage detection system (or more) appropriate for water supply networks. Secondary objectives include testing an applicable leakage detection system for Ismailia Water Distribution System (IWDS) to enhance its performance. Also, sensitivity analysis for such networks is applied to choose minimum number of sensors that can perfectly simulate leakage location and discharge in the studied networks. This study presents a generic methodology appropriate for leak detection both in location and magnitude.

A hydraulic model is created for the (IWDS) and about 1171 leakage scenarios at probable leakage nodes with different discharge ratios (20%, 30%, and 40% of maximum discharge passing through these nodes) are proposed to train ANN to recognize probable leakage locations and discharges corresponding to a wide range of sensor responses (ΔPs). Another 99 leakage scenarios with different discharge ratios (25%, 35%, and 45 % of maximum discharge passing through nodes) are proposed to calibrate the ANN model with post regression test. It's concluded that the ANN model presents a good and reliable alternative for simulating leakage detection for water supply networks. Finally, the study shows that leakage locations detected by the current methodology in 82 % of the cases tested lay within 600m or less from the actual coordinates and about 73% of the cases tested lay within 500m or less.

CHAPTER 1
INTRODUCTION

Water is one of our most precious natural resources. With the growing demands, limited resources, climate variability and uncertainties about feature of Nile flow; water conservation in Egypt becomes a top priority. Leakage is one of the primary reason for losing treated water; losses due to leakage in many countries has been estimated as third of the total pumped water in distribution networks **Liemberger et al. (2007)**. Leakage impacts the coupled natural-human system from different perspectives, including (i) serious financial damage (e.g. damage of infrastructure, losing of treated water), (ii) environmental hazards (e.g. entry of pollutants inside pipes, pooling water for long time) (iii) socially (e.g. treated water shortage, especially in the development countries). Leakage detection procedures are the main mitigation process, which can detect leakage early as soon as possible to minimize water losses due to leakage at pipe networks. Therefore, it is preferable that the appearance of a leak in a pipe be identified and located as soon as possible.

It is of interest to develop models which can simulate and detect leakage occurred at pipe networks. There are several types of leakage detection systems appropriate to water distribution pipe networks. Evaluation of such ways depends on the response time to leakage. Using hydraulic characteristic properties for such pipe network systems to detect leakage, has a good and reliable results in detecting leakage. Artificial Neural Network (ANN) technique has promising results in detecting leakage at pipe networks, which can solve non-linear and complex problems. A framework application for detecting leakage at pipe networks using ANN model, hydraulic model simulation by EPANET, and applying simple binary-based optimization analysis to identify the best pressure sensors locations have been developed. The framework is successfully applied for Ismailia water pipe networks IWPN as an actual application.

1.1 Problem Definition

The response of such model for detection leakage at pipe networks depends on simulating the equations of each operation at the system. Pipe networks have complex operation equations, which are non-linear and have multivariable function, which are very difficult to be simulated. Addition to the lack of providing communities with treated water especially at developing countries. This work has concerned with developing a frame work for pipe networks leakage detection procedures and applying it to Ismailia Water Pipe Network IWPN.

1.2 Objectives

The objectives of this study can be summarized as follows:

The main objective is to formulate a simple, yet effective leakage detection system framework appropriate for water pipe networks. This is achieved by developing a calibrated hydraulic simulation model, suggesting a technique to identify the minimum numbers of pressure sensors, and their distribution needed to monitor large water pipe networks, and detect any probable significant leakage in the network. Finally, using the