IMPLEMENTING DESIGN PROCEDURE REVIEW FOR ADESIGN OF A FLEXIBLE WATER TREATMENT NETWORK

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Abstract

This research cares about studying the several scenarios for designing water distribution networks, including the objectives and constraints associated with each case. From a flexibility standpoint, three main characteristics have been recognized as important for water systems as follows: a) costs and b) network flexibility. The broad objective of thisresearch is to investigate various design alternatives considering these four critical parameters as objectives or constraints. To understand the trade-offs between these parameters, several scenarios with varying objectives and constraints are considered. Each of these scenarios is a single or multi-objective optimization framework. The objective functions in this water distribution network design problemvary with the scenarios. A general formulation of the optimization problem is presented here. The topology ofthe system, demand locations, and demands are assumed to be known as is thecase most often. Subsequently, Pipe diameters and pump sizes are the decision variables in this research as the decision on location of pumps and tanks are usually subjected to the space constraints for a given case. Finally, this research presents how to implement a design procedure for flexible water treatment network.

KeyWords: design,water network,flexible design,

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Introduction

Some of the impacts of climate changes could affect human health, food security, water resources, and ecosystems. It is also reported that 83% of United States' green house gase missions contain CO_2 emissions (U.S. EPA, 2020). Based on the above numbers, the conclusion can bemade that CO_2 emissions play a very significant role in negatively affecting ourenvironmentwhich is whythey are usedas anindex for environmentalimpact. As per Both water supply and wastewaterdisposal require a lot of energy. The collection, transport, and finally, treating water till be capable of using drinking purposes consume massive amounts of energy, leading toreleasinghuge amounts of carbon dioxide per annum.This quantity is equal to that same pollution produced by million cars according to NRDC, 2009.

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A better design of these water infrastructure systems could no doubt achieve substantial energy savings through reducing emissions at are a son able cost. This research investigates the alternatives for designing such flexible water distribution systems considering costas objective.

In infrastructures intended to resist catastrophic natural and man-made disasters, flexibility should be seen as a crucial necessity. Historically, the design of critical infrastructure systems did not place a premium on reliability nor flexibility. However, recent years have seen increased emphasis on the improvement of reliability of critical infrastructure systems, especially after, terrorist attacks in USA and other natural disasters such as, hurricanes and earthquakes all over the world. Inside the domain of water networks, there really is no specific description of flexibility. Various previous researchers have defined and quantified reliability in different ways. Flexibility is considered as a constraint as well as an objective in this research for water network design. The main target of this work is to provide a tool for whom interested in water domain such as, utility managers, scholars, designers, etc. This tool will be useful for achieving Egypt vision 2030, for expanding water infrastructures and decrease losses from water transmission systems up to 30 %. In addition to that, complying with Paris Agreement for reducing of carbon dioxide in water systems during design and rehabilitation phases. In order to achieve this target.

The concept of how to design an optimum water network appeared in the literature since 1960s. A lot of research by scholars and academics took place for developing a model to achieve the target of how to design a water network optimally. This step made considering that the developed model consists of system constraints and several objective functions. Later, researchers made several attempts for improving the developed model that's to have a global optimum solution for any water network. However,

1. Practical constraints could be incorporated into this model to make it ready-to-use by the water industry.

2. An environmental impact in terms of CO2 emissions is explained in this research. Research may be conducted to identify and quantify the different environmental consequences of water systems, particularly water systems.

Optimization is very important in any engineering applications and must take place in different stages, such as during planning, preliminary design, normal operation, and manufacturing. Depending on the type of problem, researchers can use optimization design techniques because there are multiple techniques. There are numerous optimization techniques available, and scholars could choose one the following methods can better design the water distribution network: deterministic, random, or heuristic. The above methods can be divided into the following categories:

- Linear Method Models,
- Non-linear Method Model,
- Finally, Metaheuristics.

The preliminarily research in the domain of how to design water network optimally is dated to 1964.

Shamir's work is based on considering the diameter of pipelines of water network to be the decision variable and his work and model had been established by using gradient techniques. This model is based on the application and usage of Newton Raphson methods for establishing a steady state model, which hydraulically simulates the water network.

Furthermore, another method named a random sample method had been using by **Pitachi i**n 1966 for optimization of water networks. The previous problem is treated by another way in (1968), where **Jacoby** used non-linear integral programming methods. This method is based on approximation of the objective function by establishing a little movement nearby the design point thus, evaluate the objective function. In this approach, the diameter of pipe is a continuous variable, unlike Shamir's approach, where diameter is considered to be a decision variable and the solution is fitted to be nearby the available diameter in the market. This fit usually leads to infeasible design and adjustment is required for having an optimum solution. For the branch water supply network, the following researchers are concerned with the optimization of the branch pipe network, as follows; **Camelli et al. 1968 and Gupta et al**. during the period 1969 till 1972. The length of pipeline is highly affected both of system's total cost and resistance to the flow, where the relationship among these variables is proportional. That's why the above researchers used linear programming for obtaining a global optimum by considering the length of the pipeline to be the decision variable. In this model, the diameter is fixed firstly and repetition for the model is carried out several times for obtaining the minimum cost. Then, an extension for above method was made by Kally in 1972 for looped networks.

Kally considered the length of pipeline as the decision variable and his work is based on doing several iterations. Later, researchers classified their work and studies on water network optimal design to be either branched or looped systems. Mainly according to **Bhave**(2003) for small societies or industrial companies or agricultural purposes one can use branched water networks. Focusing will be paid for complex looped water networks too in this research. The main differences between branched and looped water network that is in the latter that due to presence of several flow distributions the demand pattern can be easily met.

An improvement to the model created by Jocoby (1968) was made by **Watanatda**(1973). The main improvements are the addition of both of nodal pressure and demand flowrate as constraints. In addition to that, **Shamir** made several improvements for **Watanatada's**model by taking several and multiple conditions for water network design and operation phases. Linear programming methods had been used by **Alperovits et al.** in 1977 for having optimum water distribution network. Optimization problems decomposition hieratical yields the targeted solution.

Linear programming methods offers improvement choices for flow distribution and other decision variables. Like Alperovits, **Quindry** created a similar formula model in 1981, among them, the node head is used to estimate the optimal cost, and the node head is considered to represent the decision variable. However, most of water distribution networks are naturally non-linear problems that's why linear programming methods unfortunately, does not provide optimum global solution. This issue had been raised by several researchers such as, Lansey and Mays in 1989, where they developed a general formula, which is valid to be used for any water distribution network. In that issue, the problem was by using the same approaches developed by Shamir. After that, the optimization model and the network solver simulator are integrated simultaneously.

Generalized reduction gradient technique or (GRG) was used for solving the optimization problem of water distribution network.By using a combination of set of different diameters and evaluation of the pressure of the node, analysis of water network is made by using the network solver. Thus, in turns the optimizer can change the diameter of the pipe if required based on the information above and the optimizer too stops algorithm process on achieving the nodal pressure or the main hydraulic constraints at the minimum network cost.

Later on, in **1987 Khang et al**. used a quasi-Newton approach for determining the direction of the gradient. The most important advantage for quasi- Newton approach that its convergence rate is rapid and faster than the primarily linear programming approaches. Nonlinear methods can be used too for having optimum design for water networks as explained by Fujiwara et. al. Problem solution is composed of two main steps. The first step is finding the global optimum solution thus, can be made using Lagrange methods and multipliers too. In the second solution phase, improvements to the optimal solution obtained in the first step are made by considering a fixed head loss, the value of which is calculated as stated in the first step, and then changing the pump heads.

An exploration was conducted in 1994 by **Eiger et al**. explained the sophistication occurred during using both above methods. According to Eiger et al., there is no change in the objective function of a network. As a result, when employing algorithm issues that are described as non-smooth, a dual theory mechanism is necessary. Similar to that the use of heuristics for optimizing, designing or solving water distribution network is made by Morgan et al. in 1985. Past studies cared about water network design were based on linear or non-linear programming tools for synthesizing and designing water networks. Unfortunately, these methods classed as very hard non-linear complex issues. In addition to, the complexity in solving the optimization problem, it's not essential to find the global optimum by nonlinear optimization approaches and usually it was found that the final solution is function on the input data to the optimizer solver Unfortunately, numerous discrete factors, such as pipelines commercial diameter, have an impact on this issue.

The term "meta-heuristic" refers to a computational method of problem optimization that repeatedly tries to improve candidate solutions for specific indications of effectiveness. Make minimum assumptions related to optimization problems and be able to search for a very wide range of possible solutions.It can use several techniques such as, stochastic optimization methods; however, the global optimum solution isn't guaranteed. From now on, the phrases "meta-heuristic" and "stochastic" will be used equally in this dissertation, and they both signify the same thing.

At the beginning of 1992, the first usage of Genetic Algorithm for optimizing water network had been made by the aid of Simpson and Murphy. The main purpose of their work is to determine the optimum cost for rehabilitation processes for simple water network system. In this minor problem, the basic GA exceeded other optimization approaches. GA is based on constructing algorithms using a combination of population genetics and several evaluation theories. That's usually made for population fitness optimization by using a two-step process which is consists of; genes mutation and genes recombining together as mentioned by Holland in 1975. As using GA in designing of water distribution networks, a case study was made by Simpson et al. for water system consists of several tanks and pipes. In this case, systems constraints are nodal pressure and tanks loading and unloading conditions GA, in this method, fitting is made for the solution.One can use technique named as a solution vector for obtaining the optimum cost. GA is comprised of three major stages, and are as follows: reproduction, crossover, and mutation. The use of both of tournament method and proper population size has been investigated by Simpson et al. in 1994. An integration for very simplified GA with EPANET solver was made by Savic.

Later on, several improvements for GA were made by Dandy et al. in 1996 to have an optimal water network. Power scaling concepts is the main principle used to achieve these modifications. The performance of the improved GA was found to be better than the ordinary methods. In addition to that, elimination of some solutions in every generation can be made as a new improvement methodology for GA and it's reported by **Montesinoset al.**1999.

Crossovers and mutations are ranked together in the modified GA. The main advantage of GA improvement is that the value of algorithmconvergence's can be raised.

One of the methods illustrated by **Halhal et al**. in 1997 is the rehabilitation strategy and how to expand water networks for large systems by applying SMGA.One of the major advantages of SMGA is that it produces a better result comparing to the GA. **Walters et al.** 1999 extended Halhal's work reported in 1997. The created model is now capable of coping with complex water distribution networks consist of pumps, reservoirs, which is a significant new feature in this study. Furthermore, messy usually, integration is carried out with network solver and GA. This integration aims for complying with the constraint in each generation. Uncertainties can exist in water network due to variation in demand pattern or leakage in water network pipelines.

It was found that there were around 13 % cost reduction and benefits based on the work done by **Neelakantan et al.** (2008). Recently, in 2010 both of **VasnandSimovic** used an improved version from GA which is called differential evolutionary DE. The main differences between DE and GA that the latter is based on determining the child solutions. In 2010, emphasis for the environmental impacts resultant from rehabilitation or constructing water distribution network had been paid so that, it's essential to build a multi- objective model, this was made by **Wu et al**. and the results obtained by GA. As indicated by Savic in 1997, GA was proven to be precise enough and capable of attaining the global optimum. Table 2.2 depicts the most frequent types of GA and models identified throughout the literature review.

Loganathan et al. and Cunha used simulated annealing for first time to improve a water network in 1995 and 1999.Thanks to **Greem et al.** for their work which used for optimization and solving water network problems by using the harmony approach in 2002. Later, in 2003 the shuffled leaped algorithm was produced byLansey and in 2003, too water network optimization statement can be solved by Maier et al. In 2007, **Baños et al.** employed an ant-colony optimization method technique to analyze the impact of a memetic algorithm for a wide water network. Later, in 2009, **Mohan** reported the optimum cost of diameter utilizing heuristic-based approaches. Finally, in 2010 stochastic techniques had been used by Jinesh to optimize water distribution networks.

Several disturbances can occur during the routine functioning of a water network, including fire, emergency, peak flows, pipeline breaks, and so on. A flexible water supply network system must be able to operate efficiently under all conditions**.** **Su et al.**, declared that flexibilityis the ability of any system to perform and perform related tasks in each period and environment. The efficiency of any water network can be measured via using flexibility indicators that's to assure that the system can be able to deliver water with the required quality, quantity and pressure to all consumers. Unfortunately, we cannot find a standard measure tool for measuring the flexibility of water distribution networks.

Due to the flexibility cannot be measured by a direct method that's because of its not considered to be a system property. Assessing or calculation of network flexibility can be made by considering the network characteristics according to Tabesh et al. in 2009. Pipeline breaks are the major factors for losing huge amount of water in water network. It was found that there is a proportional relationship between the number of pipe breaks and system's flexibility where, the water network become non-flexible when breaks increases and that's surely due to the system become unable to deliver water with required quality, quantity and pressure for all customers or consumers. Failures in pipelines can be classified according to the main cause of nature as follows.

1. Mechanical Failure: usually this occurs due to failure of one or more than one component(s) of water distribution network.

2. Hydraulic Failure: mainly, it's occurred due to demand oscillation, such as peak flow leading to an increase in water flow or head pressure at the demand node.

Care had been paid to infrastructures design especially, after the cascade terror attach in New York in 2011. There is not a fixed role in model formulation where, flexibility can be considered as a system constraint according to the work made by **Kettler et. al.** in 1985.

In the oil and gas industries, particularly pipelines, we may use a fuzzy as Sinha et al. accomplished in 2002, neural networks were used to determine and evaluate system flexibility.A comparison between artificial neural networks, fuzzy analysis and regression analysis was made by Tabesh et al. in 2009. The major goal of the comparison is to provide a comprehensive and effective picture of break rate and flexibility during the design phases of water networks. According to Syed (2005), a minimal cut set analysis is a method that may be used to evaluate various reliability techniques. As a result, we may employ it to optimize water networks.

Todini, 2000 developed a new term which, called resilience. Usually, a system's flexibility is a function on the capacity of the system considered to perform the main tasks in failures periods. So that, as the system's flexibility increases, the reliability increases too. Actually, numerous researchers, such as Farmani et al., 2006, have done work in optimizing water networks by considering system's flexibility as either to be constraints or objective functions, then trading-off among options to achieve the lowest optimum cost.

Flexibility is based on considering that when a failure of the system occurs, the internal dissipation's energy of the system will increase too. Flexibility can be measured as the additional or surplus energy existed in water distribution network. A trade- off is usually appears among the system's cost and flexibility. Water engineers and designers must take into the consideration that the network must be optimally design, i.e., with a good flexible index and not too expensive.

GAisanoptimizationtechniquethathandles optimization problems. GA evolves a superior solution for a given issue by combining selection, recombination, and mutation. Occasionally, a gene may be mutated that will result in a completely new trait intheoffspring.GAfollowsthesameprinciplestoarriveatth ebestpossiblesolutionfor a given problem.

In a randomly selected potential solution set, not manysolutions might give a desired result and thus need to be deleted; some of themcould be considered even if they fare only poorly but are promising to lead tobetter solutions in further generations. These promising chromosomes are allowedtoreproduce.These offspring would form thenextgenerationformingapoolofcandidatesolutions. Candidatesolutionsthatareworsenedbythechangesintheirchromosomearedeleted.Therandomvariationintroducedduringthemutationmayhaveimprovedthecandidatesolutionsmakingthemmoreefficientsolutionstothegivenproblem. The application of genetic algorithm is demonstrated on a sample curvefitting problem. The problem is to fit a third degree polynomial through a set ofgiven data points (Set represented as A). There are many curve fitting techniquesavailablebut genetic algorithmcouldbeused to solvethis problem.

Four of the five solutions in the second generation are determined by usinga crossover operator that is applied to successive set of parents. Thefifthsolutioninthesecondgenerationisobtainedbypassingthebestsolution fromthepreviousgeneration.Theindividualgenesofthechildsolutionareobtainedbyusingcrossoveroperatoronthegenesoftwoparentsolutionsselected. Crossover operator could be any mathematical operator between the twoparent genes.

The addition of add-in to Visual Basic for Applications makes it an even more valuable tool for design tasks, probablythemostwidelyusedoptimizationprogram.Solver employs a generalized gradient algorithm which can find solutions to smalllinear and non-linear optimization problems. Solver is limited in its capacity tosolve complex optimization problems and it is not equipped with multi-objectiveoptimization tools. Genetic algorithms as discussed in the previous chapter arecapable of handling single and multi-objective optimization problems with ease.ThismakestheuseofGAanattractiveoptionforappealing choiceswithin the field of water applications (**Savic et al. 2011**). Unlike single objectiveoptimizationwherethealgorithmattempts findingasinglesolution, which must bedesirable. Multi-objectiveoptimizationcloserto the intended users. This software was developed by the aid of Centre for WaterSystems and University of Exeter in United Kingdom (**Bicik et al., 2008**). To design and optimise the provided issue, the system offers GA to combine the strengths of single objective and multi-objective optimization. GANetXL offers a set of steady state, historical, and demographic snob genetic algorithms for single objective optimization. However, it’s recommended to use the Non-dominated Sorting Genetic Algorithm (NSGA) II for multi-objective optimization.

GANetXL is a user-friendly interface that makes it simple to formulate multi-objective problems in Microsoft Excel. GANetXL comes with a set of control buttons that may be used to traverse around the issue formation, as illustrated in Fig. 3.2. Configure Wizard tab guides the user to find the variables on the worksheet that need to be optimized, The user may pick among single-objective and multi-objective optimization, population numbers, crossover rate, mutation rate, number of genes per run, and number of iterations using the “Configuration Wizard.” A simulation tab in the “Configuration Wizard” allows the user tointegratetheoptimizationtoolwithanyexternalsimulationtoolforfitnessevaluationusingavisualbasicforapplications(VBA)macro. A dynamic library link can be used to implement the interface (DLL). After configuringthe program, the optimization The “Run” button on the interface toolbar can be used to launch the programme. The optimized performance form, as illustrated.

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