Comparative Study of Optimization Techniques in Drinking Water Distribution System –A Review

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Abstract: Water is the essential element for day to day life. Ever increasing population raises the water demand which can be fulfilled by designing and optimizing efficient water distribution network. Development of various softwares, has led to reduction of time consumption, calculations and cost of the water distribution network design. Also Artificial intelligence based various optimization techniques have been developed like Genetic Algorithm, Ant Colony Optimization, Partical Swarm Optimization, Differential Evolution, which is a boon to the water engineers for the operation, maintenance and repair of the pipe network. In this paper study is carried out to find the most suitable optimization technique for the drinking water distribution system. By comparing various optimization techniques, most appropriate system for leakage optimization of the water distribution network for drinking water pipe line can be adopted. It was concluded from the study that Genetic Algorithm is the best suited technique for the leakage optimization for the particular District Measuring Area (DMA) under study.

***Index Terms*– Artificial Intelligence, District measuring Area, Drinking, Genetic Algorithm, Leakage Optimization, Pipe Network, Water Distribution System**

I. INTRODUCTION

Water is a most important element for the sustenance of life. With the continuous rise in the population water demand also goes on increasing daily. Water is an inevitable thing for the development of any city and its socio economic growth. Critical water crises are evident in domestic, agriculture industrial use in many parts of the world. There may be a day when there will be war on water. According to research of American Water Works Association AWWA, leak detection committee (1996) recommended 10 % as a benchmark for Unaccounted For Water (UFW) of the losses are incurred during the water supply in the water distribution network. This is one of the major losses of precious treated potable water in piped network.

Latest softwares in water sector are available for the designing of an efficient water distribution system for any town or a city. This reduces the efforts of the design engineer and also gives the error free results which can be quickly implemented in practice. Similarly various optimization techniques are also available like Genetic Algorithm, Ant Colony Optimization, Particle Swarm Optimization, Differential Evolution, Tabu Search and many more, which can be compared and the most compatible system is adopted for the optimizations like cost, pumping, leakages etc for an efficient operation and maintenance of the water distribution system.

Water distribution system is the costly infrastructure and much attention has been given to the application of optimization methods to minimize design cost [1].Optimal design and operations of water distribution network (WDN) are of importance to meet the customer need at a minimal cost [2]. Operation, maintenance and design of Water Distribution Network are of utmost importance to fulfill the customer demand at a minimal cost.

For water distribution system there are many criteria, which is needs to be optimize. Various multiobjective tasks like rehabilitation, calibration and operational scheduling of water systems should be undertaken[3].In Multi objective problem helps to find number of diverse solutions, that will give best possible results for any WDN.

In urban, industrial and irrigation water supply the major optimal design of looped water distribution network is environmental and economic problem [4]. It is a challenging job for a looped WDN to reduce the cost.

Main research objective of the study is to find out the most suitable method of optimizing and thereby minimizing leakages in the water distribution system. In present work different Classification of various optimization problems, Optimization based on various Principles, Various optimization techniques and their applications are discussed.

II. CLASSIFICATION AND COMPARISON OF VARIOUS OPTIMIZATION PROBLEMS

On the basis of types of constraints, nature of design variables, physical structure of the problem, deterministic nature of the variables, permissible value of the design variables, nature of the equations involved, separability of the functions and number of objective functions, can be classified [6].Various optimization problems are classified as shown in Table 1.1.

Table 1.1: Classification of Various Optimization problems

Sr. No.	Classifications based on	Various Problems
1	Existence of constraints	(i)Constrained optimization problem having one or more constraint (ii)Unconstrained optimization problem having no constraints.
2	Nature of the design variables	(i) In subject to certain constraints, a set of design parameters that make a prescribed function of parameter minimum or maximum,. (ii) With subject to the set of constraints, design parameters that are having continuous functions of some other parameter, can minimizes an objective function.
3	Problem's Physical structure	(i)An optimal control (OC) problem is a mathematical programming problem, where each stage evolves from the preceding stage in a prescribed manner [6]. (ii) Non-optimal control problems which are not optimal control problems.
4	Nature:Equations involved	(i)Linear programming problem (LP) is that in which the objective function and all the constraints are linear functions of the design variables. (ii) Nonlinear programming problem (NLP) in this objectives and constraint functions are nonlinear. (iii) Geometric programming problem (GMP) is the objective function and constraints are expressed in polynomial form. (iv)Quadratic programming problem (QP) is a nonlinear programming problem with quadratic objective function and having linear constraints and is concave.
5	Decision variables' permissible values	(i)Integer values are only taken for integer programming. (ii)Real-valued programming problem is search to maximize or minimize a real function by systematic choosing the values, from an allowable set of real variables.
6	Separability of the functions	(i)Separable programming problems constraints are separable (ii)Non Seperable programming problem in this constraints are non seperable.
7	Objective functions	(i)Single-objective programming problem is having single objective. (ii)Multi-objective programming problem is having multiple objectives.
8	Variables' deterministic nature	(i) All the design variables are deterministic for the deterministic programming problem. (ii)All the parameters are probabilistic in Stochastic programming problem.

(Source: D. Nageshkumar,IISC)

III. COMPARATIVE STUDY BASED ON OPTIMIZATION TECHNIQUES AND PRINCIPLES

Different types of advanced optimization techniques based on their principles are classified in Table 1.2.These are nature inspired and population based also all these algorithms are applied in many engineering optimization problems which is proved to be more effective to solve some specific kind of problems. For different problems algorithms are tested to check their suitability for variety of problems. Enhancement is done either by Hybridizing or modifying the existing algorithms. Enhancement can also be done by various methods like combining the strengths of different optimization algorithms, such as hybridization of algorithms, which is an effective way to make the algorithm efficient. That can also combine the properties of different algorithms [7].

Table 1.2: Various Optimization Techniques and Principles

Sr.No.	Optimization Techniques	Principles
1	Genetic Algorithm (GA)	GA works on the principle of survival of the fittest, Darwin's theory and the Living beings' theory of evolution.
2	Artificial Immune Algorithms (AIA)	AI works on the principle of Human Immune System.
3	Ant Colony Optimization (ACO)	ACO works on the behavioral pattern of ant for finding food.
4	Particle Swarm Optimization (PSO)	PSO depends on the foraging behavior of swarm of birds.
5	Differential Evolution (DE)	This is similar to Genetic Algorithm having crossover and selection method.
6	Harmony Search (HS)	HS works with music player, based on improvement of music.
7	Bacteria Foraging Optimization (BFO)	BFO is based principle of behavioral pattern of bacteria.
8	Shuffled Frog Leaping (SFL)	SFL depends on the basic of communication amongst frogs.
9	Artificial Bee Colony (ABC)	Foraging behavior of honey bee is the principle of ABC.
10	Biogeography-Based Optimization (BBO)	Immigration of various species from one place another is main principle of BBO.
11	Evolutionary Algorithm(EA)	It works on biological evolution of human.
12	Tabu Search (TS)	It is a kind of neighborhood search [8].
13	Simulated Annealing(SA)	This also works on the principle of neighborhood search [8].

(Source: R. V. Rao and V. J. Savsani 2012)

IV. VARIOUS OPTIMIZATON TECHNIQUES

Optimization is the technique to obtain the best suited result under any existing circumstances or conditions of the problem. Hence by optimization results can be maximized or minimized as per the requirement of the study area.

There are two types of optimization methods, Classical or Traditional optimization techniques and Advanced Technique of Optimization. They are very useful to obtain optimum solution, unconstrained minima or maxima for continuous and differential function. It has a limited scope in practical applications as it involves objective functions which are not continuous differentiable [6].Advanced Optimizing techniques are shown in Table1.2.

Various Traditional techniques such as linear programming, steepest decent and dynamic programming fails to solve large-scale problems, with nonlinear objective functions, it requires gradient information so it is not possible to solve non-differentiable functions. It fails to solve optimization problems having many local optima. Hence efficient advanced optimization techniques are to be adopted [7].

Various optimization techniques are available, amongst which the most suitable technique as per the available data and study area can be selected.

Deterministic, non gradient and real time optimization are three main optimization approaches. The choices of these optimization techniques are nonlinearity or linearity of constraint [2].Population base algorithmic solution showed better performance with lesser number of iterations. As shown in the Table 1.2 from the various methods available most popularly used in the field of civil Engineering are discussed below.

4.1 Genetic Algorithm(GA)

GA is a method in which optimization is based on evolution theory. This technique provides a solution space compassing of high proportion of good solution. The GA involves three steps that is selection, cross-over and mutation which create new generation from initial population [11].

The procedure continues by considering current population as initial population up-to the termination criteria. GA is very efficient for single as well as multi optimization technique, some of the advantages of GA are as it is independent of gradient-based information, the search space of GA is large and search direction is probabilistic type therefore chance of local optimal solution is less. GA has ability to solve multi-model function, multi objectives non-linear discreet and continuous functional problems [12].

Genetic algorithm is modified to introduce operators like simulated binary crossover (SBX) and blend crossover (BLX). The mutation process is also completed through polynomial function. The process so formed is called self adaptive real coded genetic algorithm [13]. Adaptive Genetic algorithm based on Canonical GA is developed [14]. The individual bits are considered as genes. For each generation the probabilities of mutation and crossover are adapted according to fitness statistics of the generation [8].

4.2 Ant Colony Optimization

Ant Colony Optimization is a meta-heuristic strategy, inspired by real ants to give the solution to the problem was introduced in 1992 by Dorigo. To solve very complex optimization problem heuristic problem is proposed for their solution. ACO is based on foraging techniques of real ant colonies. ACO is a population based search, where the ants search for food i.e., optimized solution. Artificial ants follow a construction procedure for stochastic solution. An iterative solution is made. Pheromone trails are present on paths visited by ants. These trails vanish with time to facilitate search in new unexplored areas. Ants follow proper construction path criteria and do not take arbitrary paths; this is the constraint of a function. Hence ants find feasible or non feasible solution as per the requirements [23].

4.3 Particle Swarm Optimization PSO

Partical swarm optimization is based on flocking behavioral pattern of birds, fish and other animals. It does not require problem to be differentiable as it requires classic optimization method like quasi-Newton method and gradient descent method. All the moving particles are influenced by their local best position this leads swarm towards the best solution [5]. The particles move in the multidimensional space searching for the optimal solution. A particle represents a potential solution of the optimization problem. Every particle travels in all the different dimensional space [8].

The values of these constants have been widely studied and may vary according to the problem being studied. The dynamic calculation of these weights is presented in [15].

The swarm size is supposed to change during the process of the search method [16]. It also introduces neighborhood search and eliminates the affect of best position particles as the particle itself moves to better positions and improves performance of PSO [17]. The inertia weight is adjusted nonlinearly depending on the population diversity. It also introduces velocity mutation operator and position crossover operator. A method of learning is adapted in PSO through Comprehensive Learning PSO in [18]. It helps to overcome the problem of premature convergence. In CLPSO, the particle considers the individual best of other particles also for its own movement. A local random search (LRS) and a splitting of cognitive experience are introduced in [19]. The cognitive experience is split into good and bad cognitive factors. The MPSO algorithm combines a mutation operator and a dynamically adjusted inertial factor which are borrowed from different references. The inertial factor is defined as an exponential function[20].

4.4 Differential Evolution (DE)

Differential Evolution was introduced by Storn and Price in 1995[20, 21]. In dynamic multi-group self-adaptive differential evolution (DMSDE), information is exchanged dynamically and so the population is splited into multigroups vector individuals.During mutation from the three vectors the best vector is selected as a base vector randomly. The two stochastic vectors determine the direction of difference vector. Scaling factor and Crossover rate are two parameters which self-adapted [21].

DE generates a random initial population, which then changes and improves through mutation, crossover and selection processes applied through iterations. The main differences between the genetic algorithm and DE algorithm are the selection process and the mutation scheme that makes DE self adaptive [23]. In the process of mutation, the existing solution is changed through a scaled mutation factor. The crossover either merges the factors of two parents or a parent and a random solution. The selection process, selects the parent or child solution through tournament selection process or any other similar process. The stopping criteria applied in DE is similar to that of GA, either convergence of solutions or after certain number of iterations, provided the best solution does not change for the particular number of iterations [24, 25].

4.5 Tabu Search (TS)

The chances of Tabu search method getting trapped in local minima are dependent on the Tabu list. The procedure and rules of forming the Tabu list are altered [21].It has been mainly propagated by Fred Glover [13, 14, 15]. TS start searching neighborhood of current solution from the random solutions. When solutions are changed from iteration to another it is called a move. As the current solution moves, the neighborhood changes during iteration. The possible neighborhood search is restricted by the constraints of the optimization problem and the number of solutions. The restrictions on the movement of a solution are also placed due to the Tabu List, which contains a set of prohibited moves. The list generally is used to prevent cycling and it removes the chances of previously visited searching a solution. The size of Tabu list plays a vital role in optimization of the problem. The Tabu list changes with the search process and are replaced with newer entries. To achieve the better results, an aspiration criterion may also be introduced to override the Tabu list. The search process can be stopped if the optimum result does not change for a certain number of iterations or after some predefined number of iterations. TS on its own in not efficient to solve power optimization problem, it should be combined with some other search process to enhance the capability of the search process [16].

V. APPLICATION AND INTERPRETATIONS

5.1 Genetic Algorithm

5.1.1. Monitoring the pressure in certain parts of network is to find out the relation between pressure changes and leakage rate. For detecting leakage, it is a quick way. This relation depicts the nonlinear and complex modeling. It exists, when some mathematically modeling problems arises due to hydraulic fundamentals. This study develops a systematic procedure for developing fuzzy models is introduced that employs Genetic Algorithm (GA) and Adaptive Neuro-Fuzzy Inference System (ANFIS). It is to be done for optimizing them in terms of accuracy and complexity [24].

5.1.2. Optimizing the cost and environmental issuance of energy consumption by strategically scheduling pumping cycles is a multi-objective nonlinear problem which contains consider-able number of constraints. The solution space of this type of problem even for a small water network can be very large. It is quite difficult to finding out the boundaries associated with the solution space. For solving this kind of problems, evolutionary optimization methods like genetic algorithm, are well suited. Results are found with novel pump optimization software. Some other examples are Pollutant Emission and Pump Station Optimization (PEPSO) using a hydraulic model of a moderately sized municipal drinking water system located in Monroe, MI, USA. [25].

5.1.3. To determine the diameters of new and duplicate pipes, the status, settings and operating rules of regulating valves and operating water levels for the reservoirs, the GA model was used. Due to this, the estimated system expansion costs were minimized. The system was required to achieve minimum levels of performance like minimum pressures, subject to assume the demand patterns like maximum day and fire fighting conditions, steady-state analyses of peak hour and extended period simulation (EPS) of maximum day demands. The problem consists of the real physical and political concerns for water system planners, and it proves that the GA pipe network optimization model has the potential to become a precious, vital and practical design tool. The GA developed a series of low cost solutions. To execute this, they allowed water system planners to review potential combinations of facilities, not have been consider as part of the master planning process [26]. Recently Artificial Intelligence based techniques like Genetic Algorithms have received increased attention worldwide [9]. The researcher has also drag the attention of the readers towards the same through her work by the use of AI.

5.2 Ant Colony Optimization

Ant colony optimization (ACO) five algorithms were tested as follows

(i) Basic algorithm ant system (ii) Ant colony system (iii) Elitist ant system (iv) Elitist rank ant system (AS_{rank}) (v) Max-min ant system (MMAS) [1].Findings are- maximum and minimum ant system (MMAS) and elitist rank ant system (AS_{rank}) performed well in the study area. A complex problem of water distribution system is been solved by minimizing the network investment cost, which is subject to the pressure constraints. It could be achieving by applying single-objective constrained formulations.

The movement of ants builds solution of the optimization problem. Daemon actions are performed by the ants to execute centralized actions which cannot be performed by a single ant. Poor computational performance of ACO forms the main drawback of this technique [25].Ant colony Optimization Algorithm ACOA was applied to two benchmark water distribution system optimization problems and the results are compared with obtained using Genetic Algorithm [26]. It was found that ACOA was competent with the results obtained from GA in terms of its ability to find near global optimal solution and efficiency. Hence ACOA can be used as an alternative to GA.

ACO was also used for looped water distribution network for environmental and economic problem, in reference with urban, industrial and irrigation water supply[27].The goal of minimizing network cost with the subject to pressure constraints for the two bench mark networks resulted competent and better than scatter search[28].

5.3 Particle Swarm Optimization PSO

Under the domain of computational intelligence, PSO is an evolutionary technique (Clerc & Kennedy 2002).

By using Particle Swarm Optimization it would be easy to handle non linearity and non convexity of the problem .The search does not depend upon initial population but it has a chance to overcome of trapping to local optima, faced by conventional non linear optimization techniques. Two case studies of Hanoi water distribution network and New York City water distribution system resulted in lower number of iterations as compared to other conventional methods [29].PSO is more efficient than other optimization methods as it requires fewer objective function [30].

5.4 Differential Evolution (DE)

Two bench mark case studies on Hanoi and Newyork city models were taken under study. The objective was to minimize the cost. Results obtained were promising as compared to the previous studies and hence it was motivated to make a model for new objective function of maximizing network resilience [31].

VI. Summary and Interpretation

Table 1.3 Comparision of various optimization Techniques for water distribution System

Genetic Algorithm(GA)	Partical Swarm Optimization(PSO)	Differential Evolution(DE)	Tabu Search	Ant Colony Optimization (ACO)
Genetic Algorithm is an **E**volutionary Algorithm for solving both constrained and unconstrained optimization with the biological evolution on a natural selection process. Darwins theory of Survival of fittest.	The search does not depend upon initial population but it has a chance to overcome of trapping to local optima, faced by conventional non linear optimization techniques. It adapts foraging behavior of swarm of birds.	DE is similar to GA except that it can efficiently handle the floating point and continuous values	Tabu Search (TS) is a kind of neighborhood search.	In ACO, the colony of ants moves through adjacent solutions of the optimization problem by construction of paths.
GA is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions.	PSO , iteratively optimizes the solution of any problem with quality. It is metaheuristic as it makes few or no assumptions about the optimization problem and can search for the large space for solution	DE is similar to that of GA, it may be a certain number of iterations, or convergence of solutions or if the best solution does not change for a specific number of iterations	In TS random solution is first searched and then the current solution is searched for the neighborhood.	It is also an evolutionary technique.
It is single as well as multi objective function.	In PSO, a number of particles are randomly generated to form a population. Unlike in GA, the particles in PSO are not discarded	DE is less vulnerable to genetic drift than GA.	The tabu list keeps on updating by replacing old entries to newer one as the search progresses.	To solve very complex optimization problem heuristic problem is proposed for their solution
GAs are used to find suitable solutions from a complicated search Space.GA restricts reproduction of weak candidates, this makes algorithm converge to	PSO does not have genetic operators like GA but have particles that update themselves with internal velocity, also have memory which	DE is less taken under study in water distribution system.	TS on its own in not efficient to solve power optimization problem, it should be combined with some other search	It was found that ACOA was competent enough with the results obtained from GA, in finding near global optimal

high quality solution in few generations.	is important for algorithm. They have very few parameters to adjust.		process to enhance the capability of the search process.	solution.

VII. CONCLUSIONS AND SUGGESTIONS

As discussed above in Table1.3, from various optimization techniques of Artificial Intelligence techniques is considered for solving optimization in the civil and especially in water distribution system are: Differential Evolution, Genetic Algorithm (GA), Tabu Search, Swarm Optimization, Ant Colony Optimization. From various study it was noted that GA determines the value closer to known values compared to PSO in fewer generations. This is very essential for the leakage minimization water distribution system. Secondly comparing GA with DE it was found that GA performs better than DE in obtaining highest number of best fitness in the faster way. Tabu search takes longer to find, better solutions as compared to that given by GA .It is found that GA performs well as compared to ACO.

The main research objective of the study was to find out the most suitable method of optimizing and thereby minimizing leakages in the water distribution system, can be obtained by the Genetic algorithm. Comparative study made by the researcher in this paper comes to a conclusion that GA fulfils all the requirements of the District Measuring Area under study with the existing constraints in the system of maintaining the minimum pressure and also minimizing the leakage.

Future study on maintaining the quality of the water in water distribution system through chlorination, by using Genetic Algorithm optimization method can be implemented.

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