Review of Pipe Sizing Optimization by Genetic Algorithm

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Abstract

A Genetic Algorithm (GA) is a method of solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. GA works on the Darwin's principle of "Survival of fittest". Initialization, crossover, mutation and selection are the operations of GA. Pipe sizing optimization is a NP hard constrained type of problem with discrete pipe diameters. Many researchers have tried to solve the problem of pipe sizing with Evolutionary optimization methods like Genetic Algorithm, Ant Colony Optimization, Particle Swarm Optimization, Differential evolution, Shuffled Complex Evolution, Simulated Annealing, Memetic Algorithm, Tug of War, Water Cycle algorithm, Shuffled Frog Leaping Algorithm and Harmony Search method. A brief review has been carried out for use of Genetic Algorithm in Water Distribution Network and presented in this paper.

Keywords: Optimization, Genetic Algorithm, Water Distribution Network (WDN)

I. INTRODUCTION

Water distribution systems are interconnected networks of pipe lines, valves of various types, hydrants, pumps and reservoirs. The distribution system is an essential part of all water supply schemes. The reliability of Water Distribution System must be analyzed to assess its capability to provide water of adequate quality, with requisite quantity and pressure. Most urban water supply schemes are designed to provide water service in terms of mechanical and hydraulic reliability. However with growing concern about water quality, its reliability analysis has become an equally important area. In sprawling urban Water distribution systems, booster chlorination is desired so as to keep the residual chlorine concentration within the range of permitted minimum and maximum concentration at various demand nodes.

A water distribution network is provided to supply water to different consumers in required quantities at desired residual heads. Several optimization algorithms based on differential calculus , mathematical programming such as linear, nonlinear, dynamic etc. and evolutionary technique such as genetic algorithm, simulated annealing, ant colony optimization, shuffled frog leaping algorithm, shuffled complex algorithm, harmony search algorithm etc have been suggested for optimal design as well as expansion and strengthening of water distribution network.

Water distribution networks (WDNs) are used for transportation of treated water from the water treatment plant to the consumer. They are the most critical component of Water Supply Scheme. A standard WDN is consist of Links, Junctions, pumps, Reservoirs, Tanks and whole infrastructure that supplies water from Source to the consumer.

A link is a segment of a distribution network that transports water from one place to another. A node is a point where two or more links meet, a starting node if a link begins and end node if link ends. A source node is a starting node which receives water from outside and supplies it to the distribution network. A demand node receives water through one or more links and distributes it. A service Reservoir is constructed to take care the fluctuations in the demand. Service Reservoir fills when the rate of pumping exceeds the rate of demand and empties under reverse conditions. When a distribution network receives water from a service reservoir through gravity only it s a gravity network and when pumps are required to lift water it is pumped network. A distribution network is a grid formed by nodes, links and loops, service reservoir, pumps, valves and other accessories.

The design of WDN should be done in such a way that it can supply desired quantity and good quality of water to the consumers at sufficient pressure. The traditional design approach requires specifying the sizes of different elements of network and checking the adequacy of network and modifying it if necessary. Based on the experience and judgment of designer the initial solutions are obtained. If the specified elements are undersized the network has unsatisfactory hydraulic performance and if oversized the design is uneconomical. Thus several trials are required to obtain the hydraulic satisfactory economical solution.

The main objective of design of WDN is to obtain the most economical or optimal or cost effective solution. Traditional and optimality based approaches are similar in initial stages. In the traditional approach the networks performance is ensured first and cost is calculated at the end whereas in optimality based design approach the performance and cost of the network are combined together. The designer systematically moves from one solution to another that is better in performance and economical and stops when acceptable performance is achieved and no further improvement in cost occurs. It is possible to have different solutions satisfying the requirement of an ideal WDN and they may have different cost associated it and our aim is to find the least costly solution.

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When a physical problem is expressed mathematically the expression defining the objective (Minimization or maximization) is termed as objective function and different conditions which the objective has to satisfy are termed as constraints and entire problem consisting of objective function and constraints is termed optimization problem. The optimization problem may either by constrained or unconstrained in nature. If the constraints are nonlinear it becomes Non-linear constrained problem. The analysis of WDN comes into this category. Even for small sized network the number of possible alternate solutions is very large. The basic complexity is further compounded when pump scheduling and valve operations, reliability, water quality modeling is also considered. The discrete nature of commercial pipe size is also making the method of optimization more complicated.

Many different types of algorithms have been used for the optimum design, Rehabilitation and Operation of WDN. In an optimum design problem the purpose is to design the new network by deciding the pipe sizes for a given set of demands. In case of rehabilitation problem the aim is to propose alternatives to the existing network in order to meet new criteria. The problems faced in the optimal design of WDNs are huge. They belong to a class of problems known as NP-hard problems where the problem is intractable and it is not practical to perform a full enumeration using any rigorous algorithm. For this reason there are many examples of algorithms passing from the arena of artificial intelligence into the optimization domain. Even this very modest network would require a considerable amount of time for an exhaustive search algorithm to navigate the entire search space.

II. REVIEW OF GENETIC ALGORITHM IN WDN OPTIMIZATION

Genetic algorithm is widely used in the analysis and design of WDN.As per the basic definition an Algorithm is any procedure that uses data and modifies it according to a set of instructions. Genetic Algorithms are population based search and optimization method that simulate the logic of Darwin principle of "Survival of the fittest" or "Select the best and discard the Rest." GA provides efficient and effective technique for optimization and machine learning applications.

GA is a random search method which find, in general, near optimal solutions using evolutionary mechanism of natural genetics. When a pool of feasible solutions, represented in a coded form, is given fitness according to objective function is explored by genetic operators for obtaining new pools of solutions.

Goldberg (1989) indicated that a GA differs from the traditional search method in the following ways.

- Genetic algorithms works with coding of the parameter set not the parameters themselves.
- Genetic algorithm evaluates the population of points not a single point.
- Genetic algorithm use objective function (Pay off) information, not derivates or other auxiliary knowledge, to determine the fitness of the solution.
- Genetic algorithm use probabilistic transition rules, not deterministic rules in the generation of the new population.

The GA work by creating many random solutions to the problem. The highly fit solutions are given opportunities to reproduce by cross breeding with other solutions in the population. This produces new solutions as off-springs which share some features taken from each parent. The least fit members of the population are less likely to get selected for reproduction and so die out. To distinguish between the solutions an objective function is used. In this way over many generations good characteristics are spread throughout the population. By favoring mating of more fit individuals the most promising areas of search space are explored. GA performs a selection process in which the fit members of the population survive and least fit members are eliminated. The selection process is a step that guides the evolutionary algorithm towards ever better solutions.

Inspired by Darwin's theory of evolution, genetic algorithms use natural selection as the driving force. A genetic algorithm involves a population of individuals that are represented as chromosomes, each consisting of a set of genes that describe a solution. Individuals are selected from the population to create a mating pool based on their respective fitness levels. Individuals with a higher fitness level have a higher probability of being selected to produce offspring that represent new solutions. A very small proportion of the offspring will mutate after reproduction. Genetic operators consist of selection, crossover and mutation. Crossover involves the creation of new offspring by transforming two or more individuals. Mutation randomly changes an individual to help increase genetic diversity. Selection drives the search towards the regions with the fittest individuals i.e. the best solutions. Roulette wheel and tournament selection (Goldberg and Deb, 1991) are examples of selection operators. Tournaments are often preferred as the roulette wheel operator is characterized by rapid loss of genetic diversity that may cause premature convergence. (Goldberg and Deb 1991)

The candidate solutions in a genetic algorithm may be represented in different ways. Binary coding is a common scheme where problem variables are represented by bit combinations of 0s and 1s. Gray coding is similar to binary coding, but differs in that only a single bit changes in the representation of adjacent values of the decision variables. In real and integer coding, genes are represented as real numbers and integers, respectively. A simulation model helps ascertain the fitness of every individual in the population of solutions.

A number of GA parameters exist in literature. The selection operators may be classified as Roulette Wheel, Tournament and Random selection. The roulette wheel selection operator has inherent noise in selecting good individuals. Crossover methods may be classified as one point cross over, two point cross over and uniform crossover. GA can be used to directly work with continuous variables, binary strings or octal coded strings. The selection of appropriate values of different GA parameters such as Population size, probability of cross-over, probability of mutation is very important for satisfactory performance of GA. Their flexibility and robustness makes them universally accepted method. They do not use gradient information and make relatively

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few assumptions about the problem being solved. They can deal with nonlinear problems and non-differentiable functions as well as functions with multiple local optima. They are also readily amenable to parallel implementation.

Evolutionary techniques such as Genetic algorithm (Simpson et al. 1994; Savic and Walters 1997; Halhal et al. 1997; Prasad and Park 2004; Van Zyl et al 2004; Vairavamoorthy and Ali 2005; Wu and Walski 2005; Farmani et al. 2005; Vamvakeridou-Lyroudia et al 2005, Kadu et al. 2008;) Simulated annealing (Cunha and Sousa 1999;), ant colony optimization algorithm (Maier et al.2003, Ostfeld et al 2008), shuffled frog leaping algorithm (Ensuff and Lansey 2003),) optimization have been successfully used for minimum cost design of water distribution networks. These techniques have been applied to some benchmark problems and found to be efficient in providing minimum cost solutions.

Simpson et al. (1994) presented a methodology for the application of the GA technique to the optimization of pipe network design. They applied three operators simple GA (selection-roulette wheel, crossover-single point, and mutation) for the WDN design by using binary coding scheme.

Dandy et al. (1996) proposed an improved genetic algorithm for pipe network optimization. They used gray coding scheme for representation of population.

Savic and Walters (1997) developed a computer model GANET that involves the application of an area of genetic algorithms to the problem of least-cost design of water distribution networks. They used a binary coding rank selection method to avoid the scaling and premature convergence associated with the roulette wheel selection. The crossover operation was performed using the uniform crossover operator.

Halhal et al. (1997) demonstrated the potential of water network rehabilitation optimization using structured messy algorithm. They discussed the importance of water distribution network rehabilitation, replacement and expansion. Multi-objective approach is described; using capital cost and benefits as dual objectives. They incorporated some of the principles of the Messy Genetic Algorithm, such as strings which increase in length during the evolution of designs. The methods have been tested using two examples, the first being a small hypothetical network and the second a moderately large real system. The results showed that the structured messy Genetic algorithm is better than Standard Genetic Algorithm for the large network. Walters et al. (1998) applied GA to calibration of water distribution network models.

Kadu et al. (2008) disclosed that the real coded GA has computational time saving because it eliminates the coding and decoding of the decision variables required for binary coded GA. They developed the methodology based on critical path method suggested to reduce the search space. The method developed was better suited to systems with single demand patterns. A Hydraulic simulator GRA-NET based on the gradient method and a software tool GA-WAT is developed using C programming language. The modified GA improves the efficiency by using reduced search space, real coding scheme, variable mutation rate, self organizing penalty method, scaled fitness function and use of random GA operators.

Vairavamoorthy and Ali (2000) used a real coding scheme used a regression model that approximates the hydraulic properties. They used solution space reduction methods that limit the scope of the search, to reduce the execution times of the algorithms. Genetic algorithms (GA) can also be used in Optimization of pump operation, leakage minimization, and water quality optimization.

III. CONCLUSIONS

Based on the above mentioned review it can be concluded that Genetic Algorithm (GA) is a widely used optimization method for Water distribution network design, rehabilitation and expansion problems.

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