Optimized Water Supply Network of Pipeline by Particle Swarm Optimization with the Increment of the Utilization of Pipe

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Abstract- Water pipeline network is suffered from many issues due to their structure and tools and it leads to a concerned issue for the water managers for present and future of their network. Researchers have developed many approaches to solve the issues related to the structure of the pipelining but no any approach is developed which resolve this problem completely and provides effective water supply. The major issue faced in water pipelines is pipe breakage and then leakage of water.

This thesis work presents a methodology to optimize the cost of the pipelining and their maintenance because a large amount is spent on the repairing of the pipelines per year by the municipalities. The effectiveness of the water pipelines is basically based on the structure. In this work Particle Swarm optimization and Genetic algorithm is proposed to provide effective optimization. Genetic algorithm finds the optimum solution globally and Particle Swarm optimization optimizes local and globally. The cost optimization in PSO is reduced effectively as compare to Genetic algorithm

Keywords- Water Distribution Network, Pipeline system.

I. INTRODUCTION

Nowadays, due to increasing population and water shortage and competition for its consumption, proper and suitable utilization and optimal use of water resources is essential. Distribution networks are an essential part of all water supply systems [1]. A water distribution network is a system containing pipes, reservoirs, pumps, and valves of different types, which are connected to each other to provide water to consumers. The water distribution system is one of the major requirements in urban and regional economic development. For any agency dealing with the design of the water distribution network, an economic design will be an objective [2]. Attempts should be made to reduce the cost and energy consumption of the distribution system through optimization in analysis and design. A water distribution network that includes booster pumps mounted in the pipes, pressure reducing valves, and check-valves can be analysed by several common methods such as Hardy Cross, linear theory, and Newton-Raphson. The most important consideration in designing and operating a water distribution system is to satisfy consumer demands under a range of quantity and quality considerations during the entire lifetime for the expected loading conditions. Also; a water distribution system must be able to accommodate abnormal conditions such as breaks in pipes, mechanical failure of pipes, valves, and control systems, power outages, malfunction of storage facilities and inaccurate demand projections [5] [11]. The possibility of occurrence of each of these deficiencies should be examined to determine the overall performance and thereby the reliability of the system. In general, reliability is defined as the probability that the system performs successfully within specified limits for a given period of time in a specified environment [3]. As it is defined above, reliability is the ability of a system to provide adequate level of service to the consumers, under both normal and abnormal conditions. However, there is still not a convenient evaluation for the reliability of water distribution systems. Numerous optimization techniques are used in water distribution systems. These include the deterministic optimization techniques such as linear programming (for separable objective functions and linear constraints), and on-linear programming (when the objective function and the constraints are not all in the linear form), and the stochastic optimization techniques such as genetic algorithms, simulated annealing, Deferential Algorithm, Particle Swarm Optimization and etc.Main optimizations techniques are used to get optimal design of a water distribution system are linear programming, nonlinear programming, and various enumeration techniques [7] [8]. In this optimization study, problem is defined as minimizing the total pipe cost, subjected to both pressure and velocity constraints in the presence of given nodal demands. Since optimization of a water distribution network is rather complicated due to nonlinear relationship between parameters, former optimization techniques have some disadvantages and difficulties.

A. Pipeline System

Pipeline is the main sufficient and inexpensive mode of transportation of the hydrocarbons to land for processing and allocation. Wide-ranging business and engineering considerations go into the pipeline installation procedure. Offshore pipeline installation process has a proven track record. On the other hand, many technical challenges are encountered besides weather, water depth and installation vehicle potential and require to be addressed carefully during an installation process. Simulation of hydraulic behaviour within a pressurized, looped pipe network is quite a complex task, which effectively means solving a number of non-linear equations [2]. The solution process involves simultaneous consideration of the energy and continuity equations and the head loss function. Even in a small network of fifteen pipes, comprising pumps, valves and tanks, there are millions of combinations for the design depending of commercially available pipe sizes. Traditionally, the design of water distribution networks has been based on the designer's experience. Several trials are run by changing pipe sizes until an economically feasible solution is reached that meets the design criteria in regard to the hydraulic conformity. Pipeline engineering is a discipline in its own right. Numerous advances have been made in the installation process and the design of fitting vehicles [3] [4] [5]. There are different kinds of installation technique and the choice is made based on the project necessities and numerous other factors. Reel lay used in the thesis is one of the greatest installation techniques as the pipeline is welded in an onshore facility and spooled into the reel as very long segments. During installation of pipeline with inline structures, pipeline will be subjected to further loads in terms of bending moment, tension (axial force), and rotational effect due to the offset of COG and external hydrostatic load due to the existing of the structure. The inline structure passes through several stages of the installation process and the load on the pipeline will be different at every stage.The loading on the pipeline is particularly well-defined at the sagbend as the pipeline approaches the seabed. Sometimes they drastically reduce the limiting sea state allowable for the installation process [10]. This might have high economic consequences because of waiting on weather of the installation vessel and outcome in consequent project delays. Hence, the installation process needs to be optimized to develop the limiting sea state using buoyancy units during the significant parts of the operation.

a. Pipeline Types

There are three main types of pipeline systems discussed as follows:

b. Rigid Pipe:

Rigid pipelines are the main ordinary type of pipeline due to their ease of fabrication, low price and good mechanical properties. They are frequently made out of carbon steel and manganese with numerous other alloying materials. Several concepts of pipelines like pipe-in-pipe, sandwich pipes and particular steel pipes are examples of rigid pipeline [6]. Single carbon steel pipelines are the most generally used pipeline in the offshore industry due to their low cost and high strength. Rigid pipelines with numerous degrees of ductility, strength, toughness and weld ability are developed from shallow to deep waters. Some of the chief issues with rigid pipelines are outside corrosion and its high weight. Interior corrosion and erosion are also an issue depending upon the fluid transported [14]. They are also subjected to higher fatigue life cycles compared to flexible pipelines.

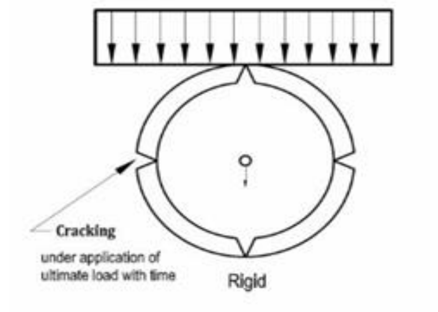

Fig.1: Rigid Pipes

c. Flexibles:

Unbounded stretchy pipes are substitute to rigid steel flow lines and risers. They are constructed from concentric layers of metals and polymeric thermoplastic materials. Each level has a particular function and each layer is added from inside outward [7] [12]. The significant layers as extended within are the carcass (Prevents the collapse of the thermoplastic liner as outcome of internal pressure), thermoplastic pipe line (Contains the hydrocarbon fluids), Steel pressure containment layers (layers that take the impact load, inner pressure and longitudinal forces) and a plastic outer sheath (Protects the pipe from external corrosion).

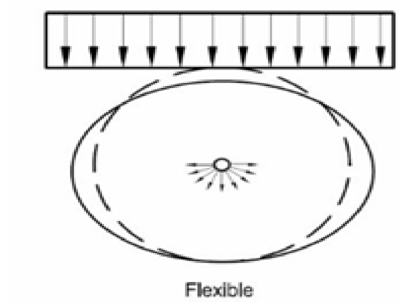

Fig.2: Flexible Pipes

d. Composite:

Combined pipes are constructed out of one of the combined materials such as epoxy resistant with glass fibre, carbon fibre or silicon nitride. This technique completely reduces the pipeline corrosion and at the same point provides great potency. The highest constraint is the manufacturing cost [3].

e. Pipeline System Components

While a subsea pipeline refers to the section of the pipeline under water, an offshore pipeline system is not restrained to it [9]. Pipeline sections extending from a start-off point,

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normally from a stand to an end point such as onshore facilities or further platform, are defined as a pipeline system.

*1. Pipe Fittings:*Fittings are the components that are used to connect the two straight pipes of tubes together**.**

Fig.3: Different types of fittings used in Piping

B. *Flanges*:

It is a device which is used to connect the two equipment and valves together. It is the second most common method used for joining after welding. Flanges are mainly made up of carbon steel, stainless steel and low alloy steel. It provides the flexibility in the maintenance process in pipelines [15]. There are some types of flanges that are following:

- Threaded Flanges
- Socket Weld Flanges
- Slip-on Flanges
- Lap Joint Flanges
- Weld Neck Flanges
- Blind Flanges

Fig.4: Different types of Flanges

C. *Gaskets:*

It is a flexible component which is placed between two other surfaces. Gaskets are used in different area like piping, cars, anti-vibration, packaging etc. Some common types of gaskets are:

- Rubber Gaskets
- Cork Gaskets
- Non-Asbestos Gaskets

Fig.5: Types of Gasket

D. Bolting:

It involves the following types as shown in figure 6 below

Fig.6: Different types of bolts

E. *Valves:*

Valves are the device which regulates controls and direct the flow of fluids by opening and closing. Some types of valves are following:

- Ball Valve
- Gate Valve
- Plug Valve
- Butterfly Valve
- Globe Valve
- Pinch Valve

1. Ball Valve

2. Gate Valve

3. Plug Valve


4. Butterfly Valve 5. Globe valve 6. Pinch Valve
Fig.7: Different Types of Valves

a. Advantages of Pipelining

- Best suited to transfer liquids and gases
- Low energy consumption
- Proper space utilization
- Properly working in all weathers

Pipelines are safe, environment friendly and accident free.

II. RELATED WORK

Zhang, Duo, et al. [1] explained the approach for sewage in-line control flow and clearly describes the free space usage of the pipes to reduce the overflow at the waste treatment plant. Basically, this work is done by using the hydraulic techniques and neural networks. Free space in the sewer system is identifying by using the detailed hydraulic model. The proposed method enhances the decision making and provides an effective response time for proposed control solution. Flow is forecasted by using the recurrent neural network. At last, the performances of the three models are compared and long-short-term memory has the capability for time series predictionZhang, Haoran, et al. [2] formulated a method which is based on the inverse hydraulic thermodynamics method and Particle Swarm Optimization. This work is done for leak detection and localization method in liquid pipelines. For numerical model continuity, momentum and energy equations are used. To analyze the virtual pipeline four types of algorithm are used. The parameters used for evaluation is accuracy, robustness, stability and false alarm rate. SIPSO algorithm is proposed and tested on two oil pipelines. This method estimates the location, coefficient and starting time of leakage.Matthews, John C., et al. [3] worked on the pipeline installation and rehabilitation methods. This work is done to find out the optimum solution for the rehabilitation of multiple pipe segments. The proposed support system is divided into two parts. Firstly it selects the optimum method which solves the problem properly. The second part analysis the quality, time and cost of the project. In this work multiple pipe segment optimization and total cost reduction. This work also presents the optimal solution by evaluating the trenchless technology.Fouial, Abdelouahid, et al. [4] worked on the irrigation distribution network.to solve the problem of the hydraulic pipeline. The rehabilitation of these pipelines is a basic need for farmers to provide effective services. To provide the cost-effective strategy computer model is used which provides the effectiveness of decision making. An algorithm is used for automatic search of the best looping position in the network.Wang, Hai, et al. [5] described an optimization model which is used to achieve the lowest power consumption. This model is able to adapt the heat fluctuation load of renewable. By using proposed method substation branch reaches the minimum excess head. The output of the pumps is sensitive to heat load fluctuation of renewable. The variation of the total pump work is analyzed by sensitivity.Wang, Peng, et al. [6] formulated the fast method for hydraulic simulation of natural gas pipeline network which is based on divide-and-conquer approach. When the size of the pipe network is increased then computation burden and time is also increased. To solve this approach fast method firstly solved the variables of multi-pipeline interconnection nodes then it divides the network into independent pipelines and solves the equation of all pipelines. The performance evaluation is done on the SPS simulator. It shows that the computation time linearly depends on the number of pipelines in the network.Wang, Bohong, et al. [7] MILP model is formulated for natural gas network design. This method determines the connection of pipelines and compressor stations. Piece-wise linearization method is also applied to this model. It solves the complicated problem of natural gas transmission network optimization. This method also reduces the construction cost.Su, Huai, et al. [8] described a method which analyses the reliability of the natural gas pipeline network. To solve the issue of uncertainty and complexity graph theory, thermal hydraulic simulation and stochastic processes are integrated. Unit states and network structure are the two factors on which supply capacity of pipeline network depends. A stochastic model is developed in this work which is based on the Markov model and graph theory.Valyukhov, S. G., et al. [9] explained an approach for the design of the flow path of the main oil pump. The maximum energy of the pump is used to optimize the flow path. The proposed model is based on the hydrodynamics process and mathematically simulated on ANSYS system. This system is combined with non-linear programming system for effective results.Rahmanifard, et al. [10] combined the Wattenbarger slab model and pseudo pressure model in net present value as the objective function. This work is based on the four variables that are HF stage, spacing, half-length and wellbore spacing. The objective function is optimized by combining the genetic algorithm, differential evolution and PSO algorithm. The computation time is reduced due to PSO. PSO has fastest convergence rate which provides the optimal solution.Wang, Yaran, et al. [11] worked on the optimization of pipelines by using air-inlet valves and air-chambers. These chambers are basically mechanical devices which are able to reduce the positive and increase the negative water hammer pressures in pumping pipelines. Air inlet is used to control the negative pressures. In this experiment single optimization model is used which optimized on the basis of the location of air-inlet valves and size of air chambers. For analysis process penalty function with minimum and maximum transient pressure is considered. Optimization is based on the genetic algorithm which solves the pipeline problem.Moghaddas et al. [12] proposed General Reduced Gradient algorithm which is used to solve the problem of meshed District heating network with multiple heat source. This algorithm optimizes the pump frequencies to reduce the total pump power. The performance evaluation is done by comparing optimal control (OC) and constant pressure difference control. The total results show that the total pump power is reduced with OC approach. Pump efficiency is not increased without considering the hydraulic constraints of district heating network.Tian, Qunhong, et al. [13] worked on the CO_2 pipeline transportation optimization using the optimal algorithm which solves the multiple uncertainties. The stepwise method is proposed to improve the optimization. The proposed method is validated by using the numerical methods which solve the multiple uncertainties and improve the design performance.Kim, Hyunjun, et al. [14] formulated the problem of the surge in which abnormal pressure is incudes by rapid changes of flow rate in pipeline systems. Various devices are also used to avoid the problem of the surge. SRV (Surge Relief Valve) is a device which is mostly used to control the abnormal pressure and discharge of flow. The performance of the SRV is depended on different parameters like design, system, and operation. This work is done for the optimization of the parameters used in SRV by using Genetic Analysis into surge analysis.Lapo, C. Mireya, et al. [15] formulated a hybrid optimization model which is a combination of Linear Programming and Genetic Algorithm. This method basically provides the optimal solution and reduces the project costs. This work is done on the shift irrigation system pipelines. This method checks the network of irrigation and reduces the cost of pipelines. The working is based on the discrete pipeline diameters.

III. THE PROPOSED METHOD

a. Proposed Methodology

Step 1 is the place for data input, afterwards proceeds to step 2 with this data. Results are obtained in step 3. Then, linear optimization objective function and constraints are formed in step 4 and runs with the prepared input file, in step 5. Output is evaluated in step 6 and 7, and then new network is formed in step 8. In step 9, hydraulic analysis of the network is performed. Step 10 is the decision place to continue or stop the run.

Step 1: Step 1 of the Algorithm: Forming Input Files

To start with the design of any water distribution network with, user prepared input files for the network are required. These files are; deneme.inp, pipeTypes.txt and loops.txt.

Deneme.inp is the text input files includes water distribution network properties. This file is used for input file for network properties and contains information about:

- Junction topographical elevations and flow demands,
- Reservoir elevations,
- Pipe lengths, assumed diameters, roughness, and topology properties.
- Hydraulic analysis options.

Deneme.inp file can be created from command menu. Initially, must be installed to computer. Afterwards, the water distribution network that is intended to be designed.

Step 2: In this step, analyses network defined by deneme.inp file.

Step 3: In this step output of the hydraulic analysis is obtained and stored in the cache memory.

Step 4: In this step, generates objective function and constraints, and then converts them into a format appropriate for input file. Gets information about; - Number of links, number of pipe types, properties of pipe types, velocity head, pressure head and reliability constraints from pipeTypes.txt file. - Loops information from loops.txt. File- Direction of flow information in the network from the cached hydraulic analysis report obtained in the previous step. After getting information, Code 1 generates objective function and constraints for optimization. Objective function and constraint equations try to find best diameters for network links to reach the optimum result. Note that, in this approach, assumed unknown parameter for any link is not the pipe diameter but the lengths of the available pipe diameters defined in the pipeTypes.txt file. Finds out lengths of predefined available pipe diameters for each link.

Step 5: In this step API linear optimizer computes optimum solution according to given input file that is prepared in step 4.

Step 6: API linear optimizer determines the pipe lengths for the used diameters and prints them.

Step 7: While optimizing the network, determines one, two or more pipe diameters for any link. Finds two types of diameter for a link.

Step 8: Extracts selected diameters in the seventh step and replaces the diameters in previous input file with these new diameters and creates new input file.

Step 9: In this step evaluates the results of last (in step 9) and first (in step 2) analysis, and then compares the flow directions obtained in two different analyses for each pipe.

Step 10: In this step checks two criteria:

• Are flow directions same between two analyses for each pipe?

• Are velocities in between the limits?

Flow directions: CATE compares new directions of flow with previous ones. If they are all same, answer to question is “YES”. If not, it returns to step 1 with the modified output file provided (output file obtained in step 8).

Velocities: controls velocities with according to minimum and maximum limits. If velocities are in limit, answer to question is "YES". If not, it returns to step 1 with the modified output file provided by (output file obtained in step 8).

If answers to all questions are "YES", finalizes the optimization.

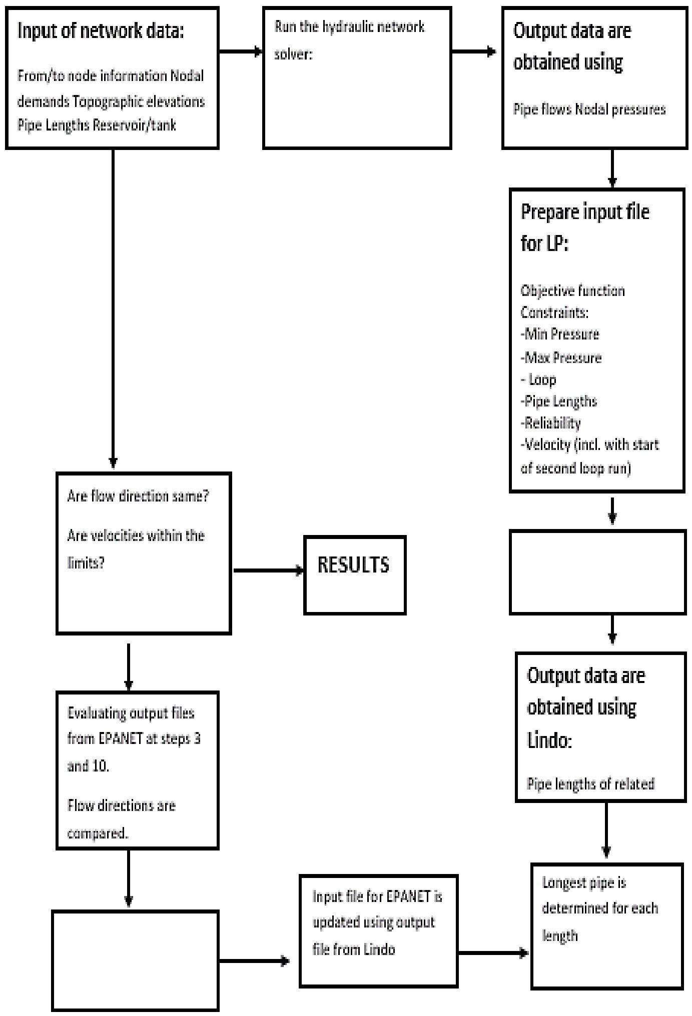

Fig.8: Workflow Diagram

b. Proposed methodology: Flowchart

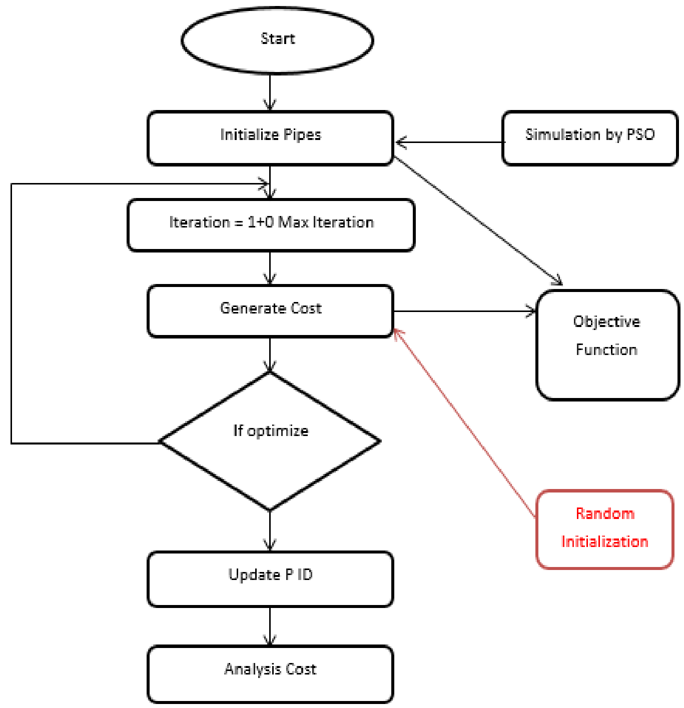

Fig.9: Proposed Flowchart

c. Proposed Algorithm

1. Particle Swarm Optimization: In PSO algorithm, every bird is denoted as a particle and have their own intelligence and some social behaviour which coordinate their activities toward food or a destination. Initially, the process is started from swarm of particles. Each particle contains a solution to the related problem that is generated randomly and in every iteration it generates an optimal solution. The i^{th}particle is bounded with a position in an s-dimensional space, in which s is the no. of particles involved in the problem. Position is determined by the values of s variables and possible solution to the problem after optimization. Ach particle i is determined by three vectors that are Current position L_i ,its best position in the previous cycles, M_i, and itsvelocity by N_i.

Current position $L_i = (l_{i1}, l_{i2}, l_{i3} \dots \dots .. l_{is})$(1)

Best position in previous cycle $M_i = (m_{i1}, m_{i2} \dots \dots \dots m_{is})$ (2)

Flight velocity $N_i = (n_{i1}, n_{i2}, n_{i3 \dots\dots\dots}, n_{is})$ (3)

This algorithm is based on the communication between the birds during the search of the food. Eacg bird look at the specific direction (its best ever attained position M_i) and later, when they communicate themselves thy go to the bird which is in the best position from the food. All the birds move towards the best position bird with a velocity that depends on the present velocity. Search space is examined by each bird from its current position.

In each iteration,eq 4 calculate the current position and velocity

$$l_i' = l_i + N_i' \quad (4)$$

The new velocity is given by the equation 5.

$$N_i' = \omega N_i + a_i rand(\ )(M_i - L_i) + a_2\, rand(\ )(M^* - L_i) (5)$$

Here,

- a_1, a_2 are two positive elements which show the learning factors.
- Rand () function generates the random number in eq 5
- ω is factor of inertia. Local and global search controls by it and it changes in every iteration of search.
- $M_i$best present solution among all.

Algorithm

Step 1: Generate random solutions.
Step 2: Search the best solution from the random solutions.
Step 3: Repeat the following step until the condition is not stopped.
3.1 Calculate the ω.
3.2 Loop i =1,2…..n

Begin

- Compute the value of objective function for solution i.
- If particle I gives the better value for the objective function, let I is the best solution.
- Compute new velocity for particle i using equation 5.
- Compute the new position for particle i using equation 4.

END

2. Genetic Algorithm: Genetic algorithm is adaptive heuristic search algorithm which is based on evolutionary ideas of natural selection and genetics. It is based on the random search which helps to solve the optimization problem. In genetic algorithm following terms are used as basic terminology.A Genetic Algorithm (GA) is a programming system that mimics normal headway as a basic deduction strategy. It is based on Darwinian's standard of improvement and survival of fittest to propel a masses of candidate solutions towards a predefined fitness. GA uses an improvement and customary selection that uses a chromosome-like data structure and propel the chromosomes using selection, recombination and transformation operators. The process usually begins with randomly made masses of chromosomes, which represent all possible solution of an issue that are considered candidate solutions. From each chromosome diverse positions are encoded as bits, characters or numbers. These positions could be insinuated as genes. An assessment function is used to figure the goodness of each chromosome as demonstrated by the desired solution; this function is known as "Fitness Function". In the midst of the process of assessment "Crossover" is used to simulate regular engendering and "Change" is used to transformation of species. For survival and blend the selection of chromosomes is biased towards the fittest chromosomes.

- **Population**: Population is the sub-set of possible solutions of the given problem.
- **Chromosomes:** it is a solution given to the problem.
- **Gene:** it is an element position of a chromosome.
- **Allele:** value taken by a gene for a particular chromosome.

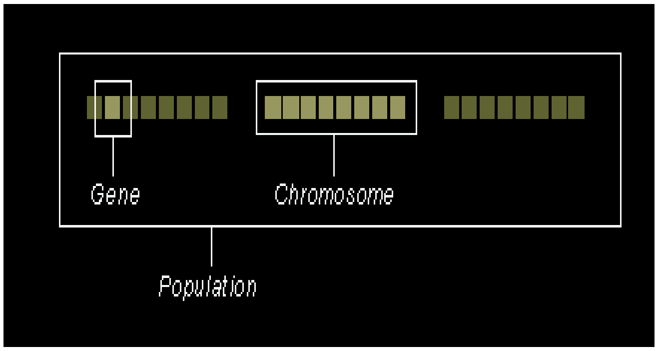

Fig.10: Search Space in G.A

Genetic Algorithm
Step1: u←0;
Step2: Init Population[P(u)]; {Initialize the population}
Step3:Eval Population[P(u)]; {Evaluate the population}
Step4: **while** not termination **do**
Step5: P'(u) ←Variation[P(u)]; {Creation of new Solution}
Step6: Eval Population[P'(u)]; {Evaluate the new Solutions}
Step7: P(u+1)← Apply Genetic Operators [P'(u)U Q]; {Next generation pop.}
Step8: t ←t+1;
Step9: **end while**

IV. RESULT ANALYSIS

a. Results Analysis

In this chapter, the result of the proposed methodology is discussed in detail. The graph represents the pipeline models for different functions like sigmoid function, convergence, and TAN. The comparison of the proposed approach which is using optimization and existing approach without optimization is also presented in this chapter.

Figure 11 depicts the relation between the iteration and convergence of the pipe Models. Here convergence is the term in which a similar task is performed by the independent resources for providing strong conclusion. Here convergence in the graph shows the best model of pipeline with PSO. The operation performed by the models on different iterations. In this graph BPSO 5 shows the effective model represented by blue line.

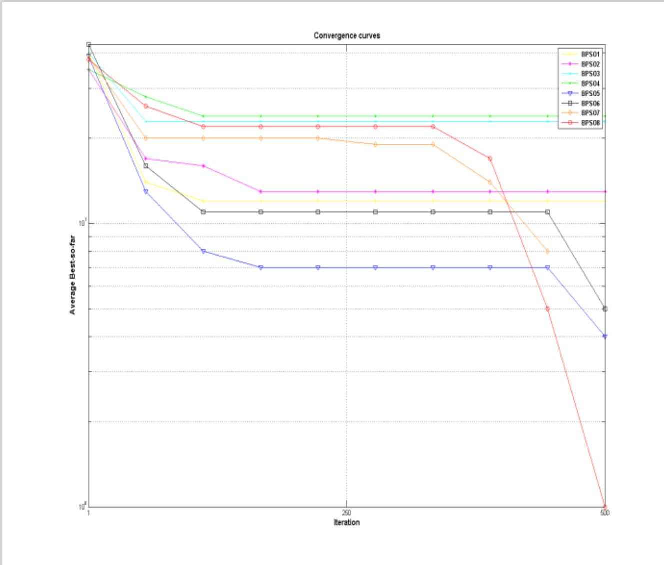

Fig.11: Graph between convergence and iteration of the Pipe models.

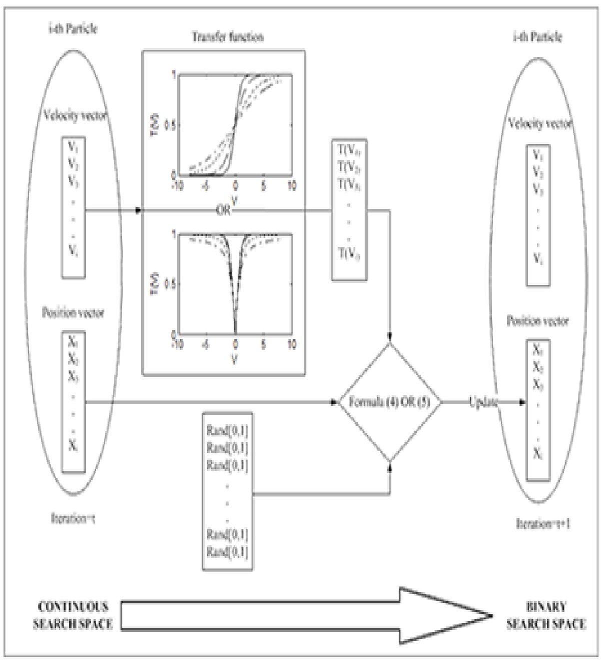

Fig.12: Flow of Continuous search space to Binary search space

Figure 12 depicts the process of Continuous search space to Binary search space. It analyse the variation between the particle and velocity on each iteration. On the basis of these iteration we get the optimized solution from them. This process is done by using PSO algorithm.

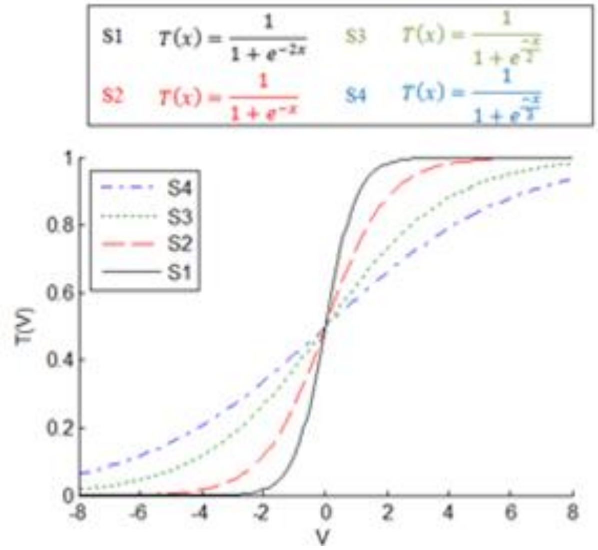

Fig.13: Graph of Sigmoid Function

Figure 13 demonstrates the variation between the particle on Sigmoid function S1, S2, S3 and S4 are the four equation of the sigmoid function and their representation on graph clearly shows the Total variation between them.

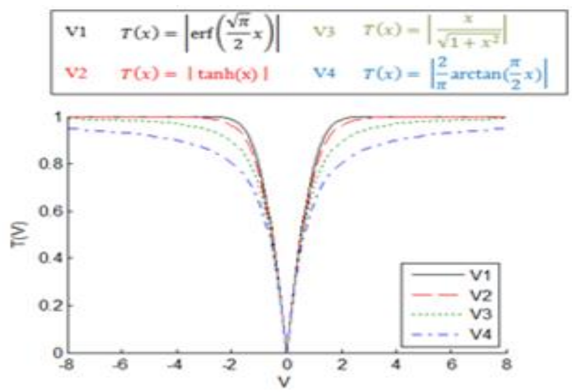

Fig.14: Graph of Tan function.

Figure 14 demonstrates the variation between the particle on Tan Function them.V1, V2, V3 and V4 represent the equation of the Tan function and also produce the graph of each equation which shows the Total variation between the given equations.

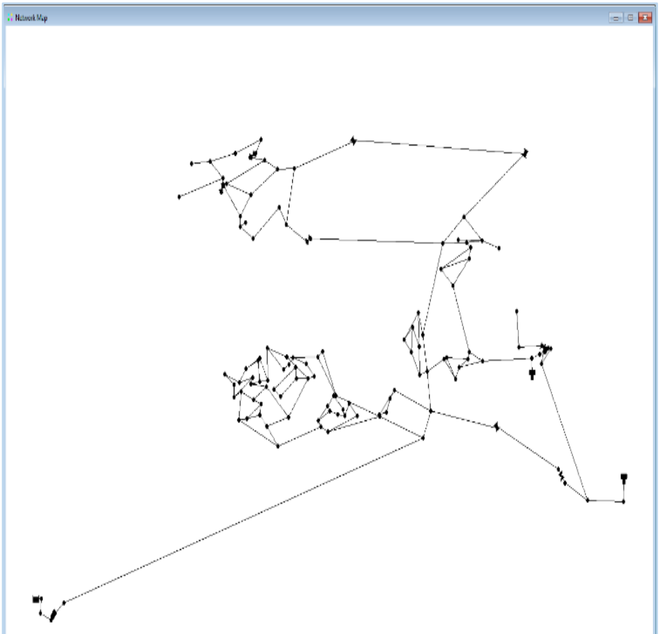

Fig.15: Network Maps 1

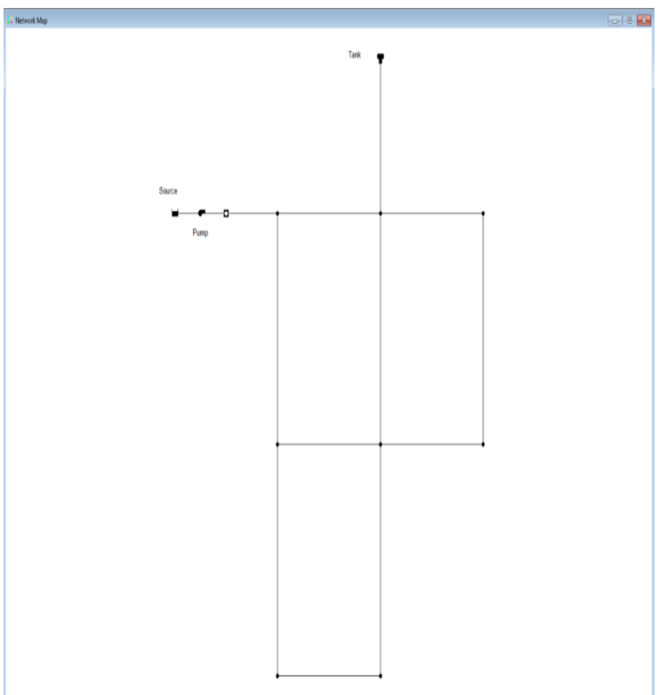

Fig.16: Network Maps 2

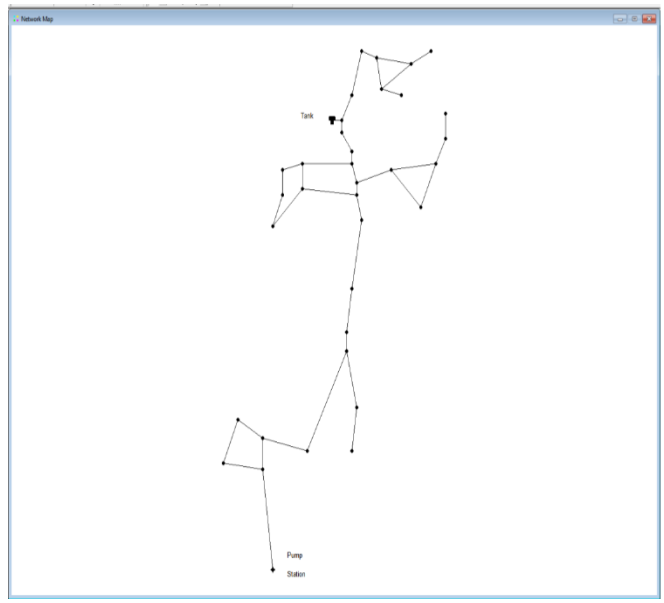

Fig.17: Network Maps 3

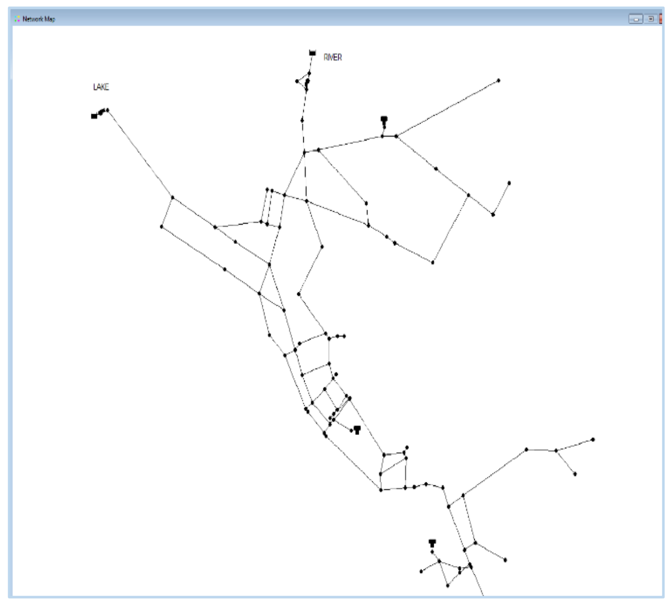

Fig.18: Network Maps 4

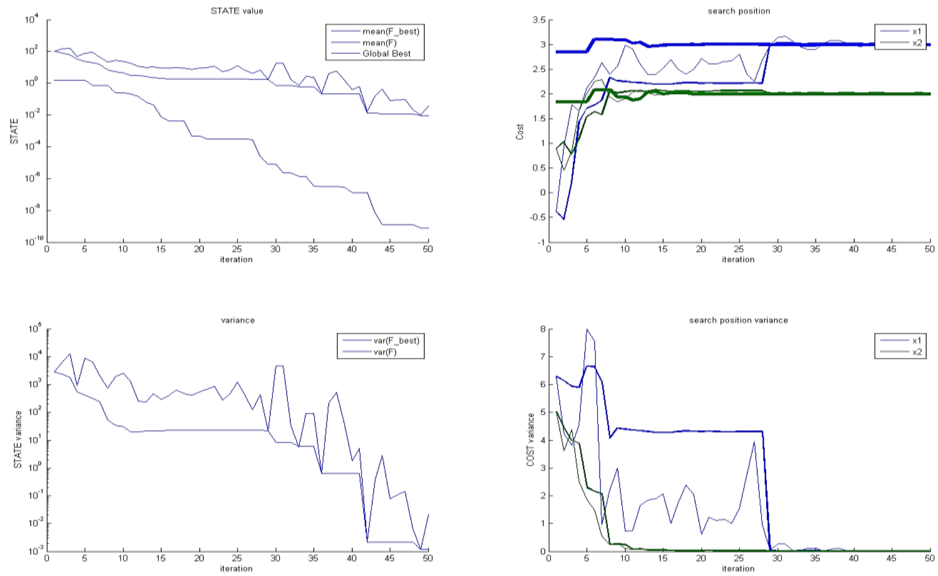

Fig.19: Graph of state value, Search Position, Variance and search position variance

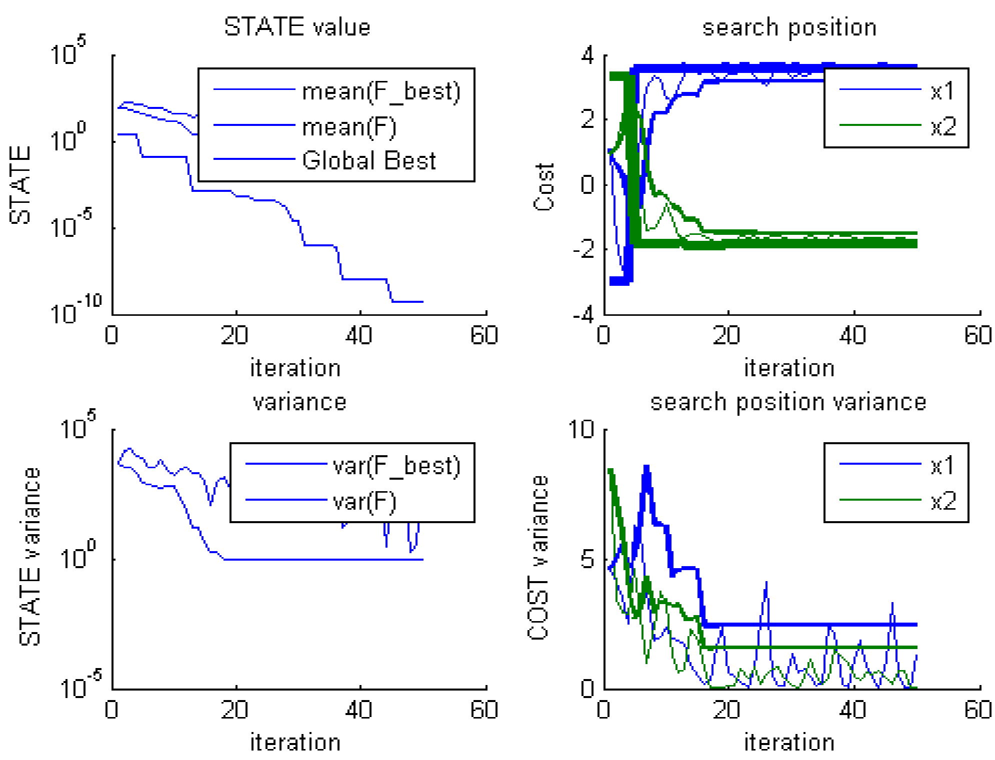

Fig.20: Graph of state value, Search Position, Iteration Variance and Iteration search position variance (without optimization)

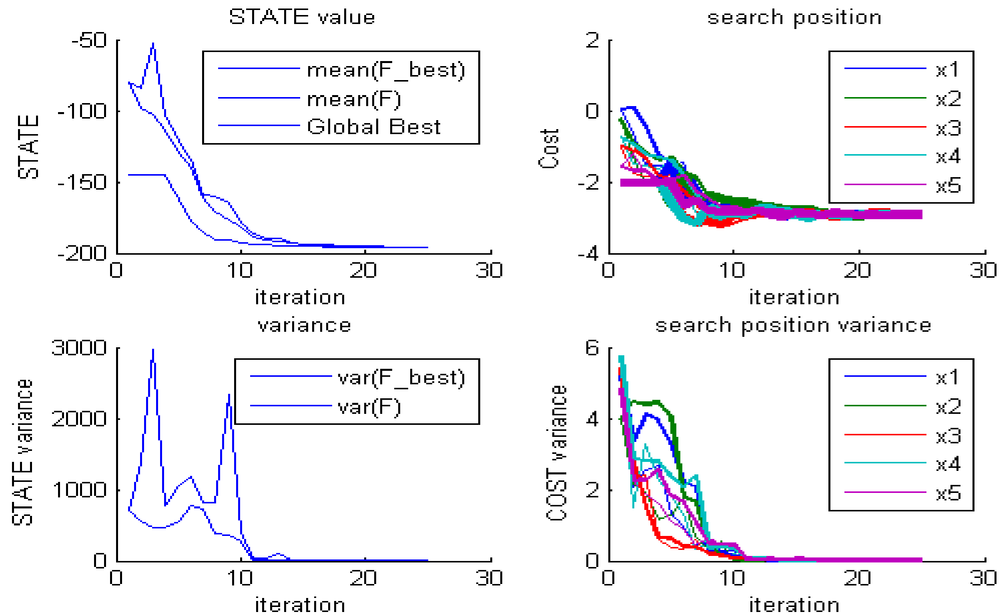

Fig.21: Graph of state value, Search Position, Iteration Variance and Iteration search position variance (PSO)

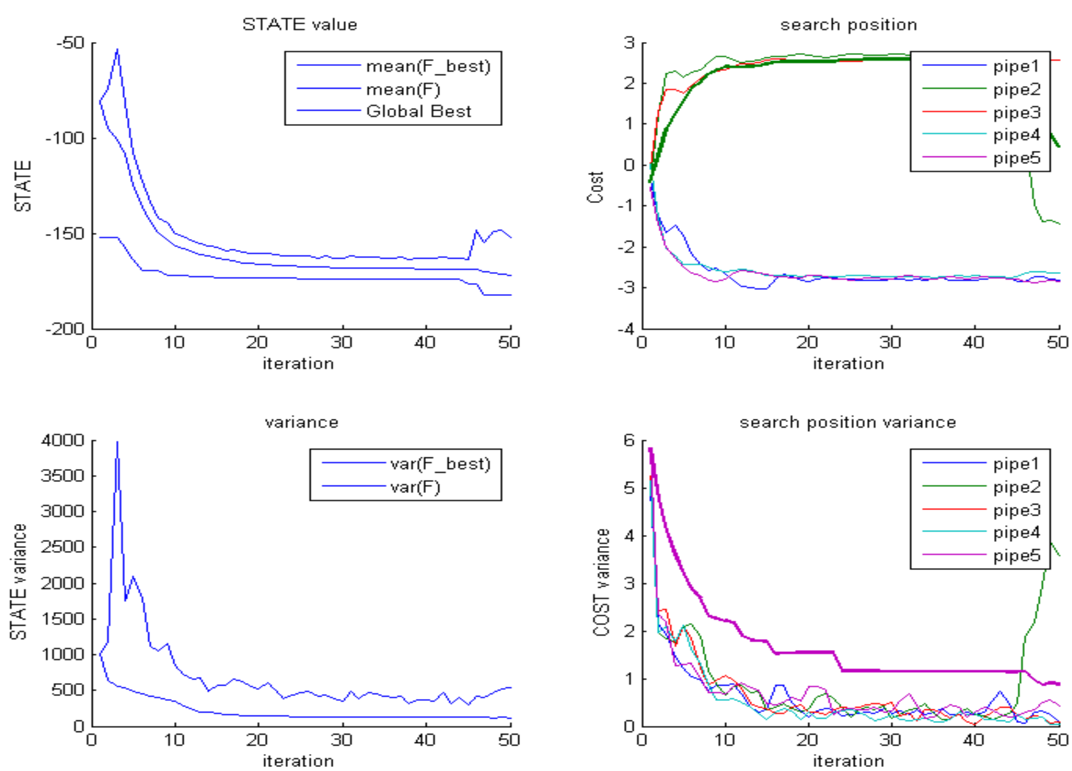

Fig.22: Graph of state value, Search Position, Variance and search position variance **(GA)**

V. CONCLUSION

The problem of pipe network design for gravity systems is usually formulated in the following way. For a given layout of pipes and specified demands at the nodes, find the combination of pipe sizes that gives the minimum cost, subject to the following constraints: 1. Continuity of flow must be maintained at all junctions or nodes in the network. 2. The head loss in each pipe is a known function of the flow in the pipe, its diameter, length, and hydraulic properties. 3. The total head loss around a loop must equal zero or the head loss along a path between two reservoirs must equal the elevation difference. 4. Minimum and maximum pressure head limitations must be satisfied at certain nodes in the network. 5. Minimum and maximum diameter constraints may apply to certain pipes in the network. The PSO codes the pipe sizes available for selection as binary strings. We have used a simple three- operator Particle swarm optimization. The results from the PSO technique have been compared with both complete enumeration and nonlinear optimization. One may only use complete enumeration for pipe networks with relatively few pipes. Nonlinear optimization is an effective technique when applied to a small network expansions such as for the case study network; however, the problem of rounding up and down of the continuous solution to discrete pipe sizes must be addressed. The nonlinear programming method only generates one solution. The PSO technique generates a whole class of alternative solutions close to the optimum. One of these alternative solutions may actually be preferred to the optimum solution based on other non-quantifiable measures. This is a major benefit of the genetic algorithm method. The genetic algorithm technique is in its infancy, and further developments should provide improvement in these search methods for practical problems.

VI. REFERENCES

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