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Developing New Algorithm and Its Application on Optimal Control of Pumps in Water Distribution Network

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***Abstract*—**In recent years, new techniques for solving complex problems in engineering are proposed. One of these techniques is JPSO algorithm. With innovative changes in the nature of the jump algorithm JPSO, it is possible to construct a graph-based solution with a new algorithm called G-JPSO. In this paper, a new algorithm to solve the optimal control problem Fletcher-Powell and optimal control of pumps in water distribution network was evaluated. Optimal control of pumps comprise of optimum timetable operation (status on and off) for each of the pumps at the desired time interval. Maximum number of status on and off for each pumps imposed to the objective function as another constraint. To determine the optimal operation of pumps, a model-based optimization-simulation algorithm was developed based on G-JPSO and JPSO algorithms. The proposed algorithm results were compared well with the ant colony algorithm, genetic and JPSO results. This shows the robustness of proposed algorithm in finding near optimum solutions with reasonable computational cost.

***Keywords*—**G-JPSO, operation, optimization, pumping station, water distribution networks.

I. Introduction

OPTIMIZATION in mathematics and computer sciences is a process of selecting or finding the best member in a set of available options. Each process has optimizing potential and complicated issues can be modeled in engineering, economics and commercial sciences such as optimizing issues. The goal of modeling the optimizing issues is minimizing the time, cost and risk or maximizing the benefit, quality and efficiency. In recent years, the researchers have found proper findings in most of complicated optimal issues by applying innovative methods.

In recent decades, different methods were developed for solving optimal issues. These algorithms are classified in two classes of definite and probable problems [1]. Definite algorithms are local searching methods based on gradient which needs basic movement information for finding a possible solution. In cases in which solution space is non-convex, finding global optimal solution using these algorithms is not simple [2]. In other words, some issues which are non-convex include multiple local optimal in their solving space. In such issues the quality of final solutions need definite initial values. Because of this, the researchers use optimal probable algorithms in their researches. These algorithms are inspired from natural phenomena and do not need moving information for finding any solution. The most important probable optimal algorithms include genetic algorithm, forbidden search, group ingredients optimization and ant colony. In recent years, global local combined algorithms were applied successfully for solving non-convex issues [2]. These algorithms combined the local and global searching aspects in their structures for efficient searching. In these algorithms the searching process will be started with multiple points and searching for solution space will be started from these points. Then local searching algorithms find optimal solution in these spaces. It is possible that in these algorithms the searching space can be in the form of continuous or discrete. One of these algorithms which was very usable in water engineering domain is group ingredient optimizing algorithm. In this paper first of all, it is tried to develop this algorithm in discrete space and create the ability to solve discrete graphic issues and then measure its performance in optimal operation of pumps in water distribution network. So in the following, a short review will be done on the works which were done in this field.

A main part of consuming energy in water distribution networks is related to available pumps in network. With determining proper schedule for operating from the pumps of water transferring system we can reduce the consuming energy cost significantly.

The case of pump's optimal operation in water distribution network is a part of a large non-linear problem, because the problem constraints and goal functions are non-linear and the number of decision variables and issue constraints are very much. The goal function of such an issue is minimizing the operation cost from pumping stations during a planning horizon, which the system pumps out the water during this time [3].

In recent years, many researches were made on optimal pumps operation and pumping stations. For example, [4] did some researches in the field of optimal operation of pumping stations (consuming electricity cost). In their research, genetic algorithm was used as optimizing algorithm. Mathematically, the optimal design and operation of pumping stations is a large-scale nonlinear programming problem because of the size of the problem in terms of the number of the decision

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variables and nonlinearity of the constraints. The objective in a design and operating of irrigation pumping system problem is to minimize the annual depreciation cost of construction and operations while satisfying system constraints to account for the hydraulics behavior, bounding constraints on decision variables, and other constraints that may reflect the operator preferences or system limitations.

Many researchers have developed optimal control formulations to minimize the operating costs associated with water distribution pumping systems. Various optimization techniques have been applied to the operational optimization problem, including linear programming [2] nonlinear programming [3], [4], dynamic programming [5], fuzzy logic [6], nonlinear heuristic optimization [7], [8], genetic algorithms [1], [9]-[11], particle swarm optimization [12], ant colony optimization [13].

Finding optimal schedules for pumps in a water distribution network (WDN) is a difficult task for researchers and managers alike. A careful scheduling of pump operations may shift workload to cheaper electrical tariff periods, reducing the cost of energy consumed by pumps. Furthermore, energy savings can be accomplished by pumping water when tank levels are lower, and combining the operations of several pumps efficiently. On the other hand, (future) pump maintenance costs caused by pump operations cannot be easily quantified, so surrogate measures are used to estimate it. The most common of such measures is the total number of pump switches: frequent switching (on/off) causes wear and tear of pumps and pressure surges throughout the network, and, hence, increases future maintenance costs. These maintenance costs can be considered in the optimization problem by limiting the number of pump switches [14]. In this paper, by applying innovative changes in JPSO algorithm jump nature, the ability for solving problem will be engendered in it. Then to investigate the proposed algorithm ability, at first, the mathematics complex function of Fletcher–Powell (five dimensions) and then pumps optimal control issue in water distribution networks will be studied and the results will be compared with ant colony and genetic algorithm.

II. A Review on Non-Continuous PSO Algorithms

Creating a simple change in standard PSO nature for the first time, [15] used this algorithm for solving the non-continuous problems. In standard PSO, the speed means particle movement vector in searching space, but in discrete space, this meaning is not true anymore. In this developed algorithm, the threshold speed is a possibility based on which the variable X_{ij} has the value of 0 or 1. In this algorithm, the speed timing way is mostly like the standard PSO but the weight inertia parameter (ω) is not applied in it.

$$v'_{ij} = v_{ij} + c_1 \text{rand}()\left(b_{ij} - x_{ij}\right) + c_2 \text{rand}()\left(g^*_j x_{ij}\right) \quad (1)$$

In order to specify a new value for $X_{ij,}$ at first, the speed value should be changed to a number between zero and one. For this purpose, Sigmoid function S(X) will be used.

$$S(x) = \frac{1}{1+e^x} \quad (2)$$

Then the value of variable X_{ij} will be selected accidentally, and (3) will be attained.

$$x'_{ij} = \begin{cases} 1 \text{ if } \left(\text{rand}() < S(v'_{ij})\right) \\ 0, \quad \text{otherwise} \end{cases} \quad (3)$$

References [16], [17] based on PSO non-continuous algorithm of [15] presented similar PSO algorithms for solving problems which were coded as zero and one. The way of updating the speeds is the main difference of these two algorithms with non-continuous PSO algorithm of [15].

Reference [18] innovated a new method based on PSO for solving combined optimal problems. By pointing to this subject that in discrete space the speed vector cannot be described as a particle movement vector, they ignored it involving in their method. In this method, a particle movement in a discrete space is described as particle jump from a response to another one. This jump can be resembled as the jump of frog on a lily pad. The name of this algorithm is jumping PSO (JPSO).

III. Jumping PSO (JPSO)

In this method, the situation of a particle $X_i = (x_{i1}, x_{i2}, \ldots, x_{is})$ (s is the number of decision variables) is studied as an acceptable response for combined optimal problem. The particle situation in each repeat will be changed through jumping from one response to another one. There can be 4 kinds of jumping in any repeat, but one of them will be selected. The first kind is a jumping which is entirely accidently. The second kind is a jumping toward the best previous situation of particle $B_i = (b_{i1}, b_{i2}, \ldots, b_{is})$. The third kind is jumping toward the best situation in the particle neighborhood $G_i = (G_{i1}, G_{i2}, \ldots, G_{is})$, and the forth kind is jumping toward the best situation in the repetition $G^* = (g_1, g_2, \ldots, g_s)$.In this method B_i, G_i and G^* are called navigator. Components' situation timing is described by (4):

$$X_i = c_1 X_i \oplus c_2 B_i \oplus c_3 G_i \oplus c_4 G^* \quad (4)$$

c_1 is the possibility that the jumping will be done accidentally (jumping type 1). With the possibility of c_2, the jumping will be formed toward B_i (jumping type 2) and with the possibility of c_3, the jumping will be formed toward G_i (jumping type 3) and finally with the possibility of c_4, the jumping will be formed toward G* (jumping type 4). The set of values $c_{1,}$ $c_{2,}$ c_3 and c_4 are equal to 1 and in each phase, only one of them will be selected. In each phase the jumping will be done step by step. Suppose that one of the jumping kinds is selected for the considered particle with the selection possibility of c_i. In the first jumping step, one of the decision variables is selected accidentally and with a steady possibility and its value will be changed. In jumping type one, the changing in the value of decision variable is entirely accidentally, while in jumping type 2, 3 and 4 the value of decision variable is substituted with its same value in navigator. After the completion of the

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first step, the accidentally number ζ with steady possibility is selected between zero and one. If ζ was smaller than $c_{i,}$ then another decision variable is selected accidentally and with steady possibility and its value will be changed, otherwise the jumping will be stopped.

IV. Richmond Real Network

In order to examine the efficiency of presented model, the proposed algorithm in Richmond water distribution system, which is a real system located in English, is used. The calibrated network has seven pumps, six tanks, one reservoir, 948 links and 836 nodes (Fig. 1). Richmond network description can be found in [8]. This network was studied for the first time by [19]. All the tanks of the network should be filled up to 95% at the first of the period of electricity climax. Table I shows the statistical results of consuming electricity cost of distribution network pumps in 25 run of program with $N_s \leq 21$ and $N_s=21$ for two algorithms JPSO and G-JPSO. The comparison of the results with the ant colony and genetic algorithm shows the priority of proposed G-JPSO algorithm.

Figs. 2 and 3 show the operation instruction from available pumps in network during 24 hours of operation period with $N_s \leq 21$ and $N_s=21$ resulted from G-JPSO and JPSO algorithm.

V. Conclusion

In this research, by performing the changes in jumping nature in JPSO algorithm, the ability to solve the discrete graphic issues has been created. This algorithm is tilted as G-JPSO. At first the proposed algorithm was used for solving the mathematics problem of minimizing Fletcher–Powell complex function, which finally the resulted responses were much better than ant colony algorithm. For determination of the consuming electricity cost, the need of consuming nodes and problem limitations include minimal required pressure in each node, minimal and maximal tanks' height and so on be risen up. The other limitation includes the times of turning the pumps on and off that in both statuses the goal function was performed. The first status of each pump's on – off status was determined three times and the second status of each pump's on–off status was determined utmost three times. Operation program includes determining on and off statuses of each pump during the daytime in the time range of 1 hour. The results showed that the response of goal function of JPSO algorithm is better than Hybrid GA algorithm, but the power of ant colony algorithm for finding the minimal response was more than the two other algorithms in both statuses. But generally the worst response which was yield in 25 times of model execution was lower than the two others. Also, the proposed model was evaluated for Richmond real network that the significant priority of proposed algorithm than genetic and ant colony algorithm was considered. The cause of this is in solving these problems by making a graph to searching space will decrease and the possibility to reach an optimal response will increase, which in this research by creating this ability in JPSO algorithm the searching space is decreased and the power of algorithm for finding an optimal response is increased.

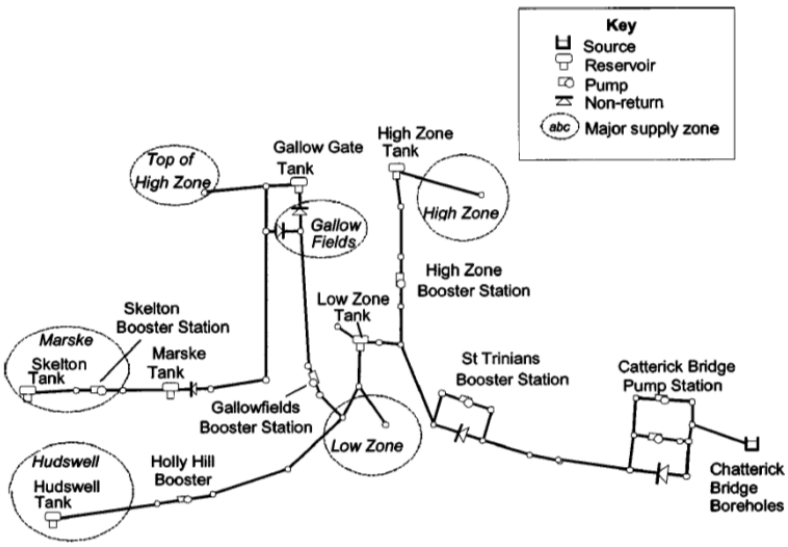


Fig. 1 Richmond real network

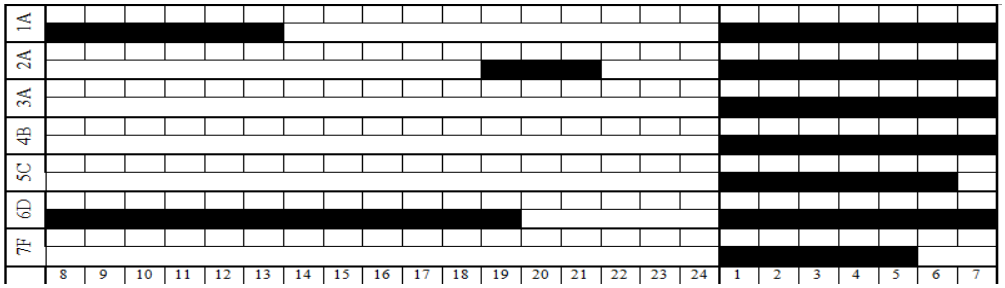


Fig. 2 Optimal operation of pumps during 24 hours of operation period ($N_s \leq 21$)

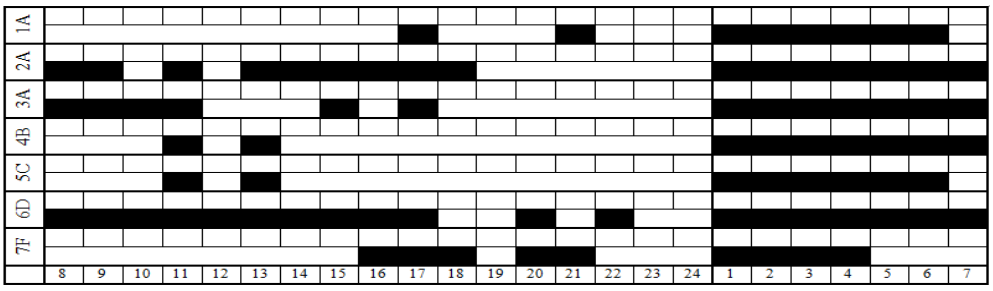


Fig. 3 Optimal operation of pumps during 24 hours of operation period ($N_s \leq 21$)

TABLE I
CONSUMING ELECTRICITY COST OF DISTRIBUTION NETWORK PUMPS IN 25 RUN OF PROGRAM WITH $N_s \leq 21$ AND $N_s=21$

	Algorithm							
	G-JPSO (8,000 evaluations)		**JPSO (8,000 evaluations)**	**ACO*(8,000 evaluations)**		**ACO*(50,000 evaluations)**		**GA*(100,000 evaluations)**
	$N_s \leq 21$	$N_s=21$	$N_s \leq 21$	$N_s \leq 21$	$N_s=21$	$N_s \leq 21$	$N_s=21$	$N_s \leq 21$
The Best	24805.4	32631	37314.7	33683.3	34319.9	32728.5	32581.4	37266.5
Median	30116.1	35576.5	37697.8	36069.7	36699.7	33747.5	33634.1	41099
The Worst	33689.5	36500	42782.3	38017.3	39052.4	35754.5	34464.8	43508

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