Using Genetic Algorithms in Pump Scheduling to Reduce the Pumping Cost[1]

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Abstract

Increasing demand of water consumption in the cities causes that the provision systems to become more and more complex. The task of optimizing depends on the variables to be considered and the objectives to be taken into account. Also the pump scheduling becomes a complicated task when the pumping station systems grow. In this paper, pump scheduling is applied to optimize two objectives: the cost of electrical energy of the pumping and the cost of maintenance of the pumps. The pump scheduling problem is solved by using Genetic Algorithms with Matlab software and the pumping cost is reduced by more than two percent when the water is pumped during the periods of low tariff (the periods of low electricity consumption).

Keywords: Water pumping stations, Pump scheduling, Genetic Algorithms.

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1. Introduction

In general, a pumping station contains a set of different capacity pumps that pump water to one or more overhead tanks. These pumps work in combination to pump the necessary amount of water; there are some restrictions of the problem (like the maximum capacity of overhead tank, taking care of the demand). Therefore, in the moment some pumps may be working while others may not. Pump scheduling is the set of all the pump combinations chosen for every time interval of the scheduling [1].
Ormsbee et al, Presented a detailed review of linear, non-linear, integer, dynamic, mixed and other kinds of programming used to optimize a single objective: the electric energy cost [2]. Also, they introduced the number of pump switches as an alternate way to evaluate the pump's maintenance cost, which became the second objective considered until that date. In order to minimize the operating costs associated with water supply pumping systems several researchers have developed optimal control formulations [2]. Mays, list and classify various algorithms that have been developed to solve the associated control problem [3]. In the past few years, Evolutionary Computation techniques were introduced in the study of the optimal pump-scheduling problem. In fact, Mackle et. al, presented a single objective optimization (electric energy cost) using Multi-objective evolutionary algorithms (MOEA) [4]. Also, Savic et al, proposed a hybridization of a Genetic Algorithms (GAs) with a local search method, to optimize two objectives: electric energy cost and the number of pump switches [5,6]. In addition, Schaetzen presents a single objective optimization using GAs considering system constraints by establishing penalties [7].
In this paper, a genetic algorithms with Matlab software is applied to minimize two objectives (electrical energy consumed and maintenance cost) for solving pump scheduling problem.

2. Importance of research and its objectives

The problem in water pumping station and its distribution system affect on water demand from the community. The main goal is to minimize the cost of pumping water, while satisfying several hydraulic and technical restrictions and keeping the physical and the operational constraints within limits. There are two kinds of costs associated with the operation of pumps: electrical cost and maintenance costs. Also, we must insure that water during a 24 hour period, and daily, is satisfactory for the community.

3. Methodology and tool of research

The research starts with an introduction that presents the pumping station components and the importance to use a genetic algorithm in this field. Also, a genetic algorithm (GA) for pump scheduling and the pumps consumption of electricity relation analysis are presented. The coding that helps us to present every potential solution is explained. Finally, the results and conclusion are presented.

4. Genetic algorithm (GA) for pump scheduling

The GA is an adaptive method trying to imitate the biological and genetic processes. It is a successful method for optimization. This method will always find reasonably good solution. The GA works with set of possible solutions simultaneously, and this set is called population [8, 9]. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. The genetic algorithm can be applied to solve a variety of optimization problems that are not well suited for standard optimization algorithms [10].

The genetic algorithm optimizations procedure can be summarize as below [11]:

1. The algorithm begins by creating a random initial population.
2. The algorithm then creates a sequence of new populations. At each step, the algorithm uses the individuals in the current generation to create the next population. To create the new population, the algorithm performs the following steps:

- Scores each member of the current population by computing its fitness value.
- Scales the raw fitness scores to convert them into a more usable range of values.
- Selects members, called parents, based on their fitness.
- Some of the individuals in the current population that have lower fitness are chosen as elite. These elite individuals are passed to the next population.
- Produces children from the parents. Children are produced either by making random changes to a single parent — mutation — or by combining the vector entries of a pair of parents — crossover.
- Replaces the current population with the children to form the next generation.

3. The algorithm stops when one of the stopping criteria is met.

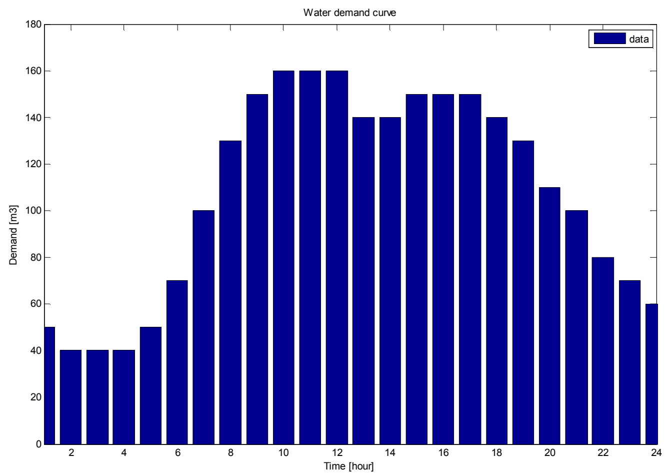

Figure (1): Water demand curve

In figure (1), the volume of water demand from the community is given as variable in time.

And the amount of water must satisfy this demand. The maximum water consumption is between 9 ~ 11 a.m. and the minimum is between 2 ~ 4 p.m. (post meridian) [12].

As shown in figure (2). The hydraulic model consists of:

1. An inexhaustible potable water source.
2. A water pumping station with n pumps used to pump water from a water source to the overhead tank.
3. Overhead tank of water storage which supplies water on demand to a community. The maximum storage volume in the reservoir is set to 800 m^3.
4. A main pipe that leads the water from the pumping station to overhead tank.

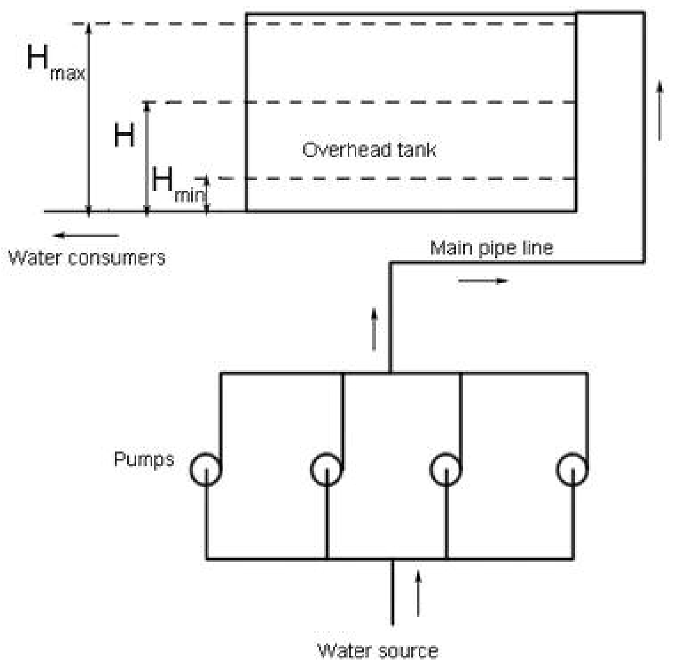

Figure (2): Water supply system

In our system we have four centrifugal constant speed pumps with different capacities, and every pump can be switched on or off during any time interval. The pumping capacities are considered constant for all the combinations during the intervals (the pumping capacity equal to the sum capacities of all pumps which are switched on). In table (1) we can see pump capacities and the amount of electricity used in one hour for /RAAS AL-AIN-LATTAKIA/ pumping station. These pumps are connected in parallel together. It can pump water from different water sources to one or more reservoirs.

Table (1): Pumping capacities

Pump	Amount of water pumped in one hour [m^3]	Amount of electricity used in one hour [kWH]
Pump1	30	30
Pump2	30	30
Pump3	50	44
Pump4	100	80

5. Analysis

The purpose of pump scheduling is to optimize:

❖ The first one is the cost of electrical energy consumed by the pumps.

It is the cost of electric energy consumed by all pumps of the pumping station. In addition, there is an important factor where, the electric energy cost is not the same during the whole day; we can consider the following charge structure:

Minimum cost ($c_{\min}$): from 0.00 to 17.00 hours and from 22.00 to 24.00 hours.

Maximum cost (c_{max}): from 17.00 to 22.00 hours.

The mathematical equation is developed to calculate the electric energy cost C_e is:

$$C_e = c_{min}\sum_{i=1}^{i=17} c(m_i) + c_{max}\sum_{i=18}^{i=22} c(m_i) + c_{min}\sum_{i=23}^{i=24} c(m_i)$$

i : Time interval of the period of optimization.

m_i : Combination of pumps in the interval i .

$c(m_i)$: Electric energy consumed by pump combination m_i .

The water should pump as much as possible during the periods of low tariff and the periods of low electricity consumption. Then, we can save two percent of consumption energy by pumps.

- The second one is the pump's maintenance cost.

The maintenance cost, in many cases, is equal or more important. We can introduce The concept of the number of pumps switches is an option to measure maintenance cost, by this way, pump's maintenance cost can be reduced indirectly by reducing the number of pumps switches.

6. Coding

The importance of the coding in our problem is to present every potential solution. We can do it by using binary alphabet, and each pump during a certain time interval will represent by one bit of the string. Where, if the bit's value is zero, it means the pump is switched off, or if the bit's value is one, it means the pump is switched on during this time interval. For one hour, there are 2^4=16 possible pump combinations. A string consisting of 24×4 bits describes the problem completely. Thus, the overall number of possible solutions to the pump scheduling problem is

2^{96}. In table (2), We can see possible pump combinations for one hour.

Table (2): Possible pump combinations.

Pump 1	Pump 2	Pump 3	Pump 4	Volume pumped in one hour	Electricity consumed in one hour
0	0	0	0	0	0
0	0	0	1	30	30
0	0	1	0	30	30
0	0	1	1	60	60
¦	¦	¦	¦	¦	¦
1	1	0	0	150	124
1	1	0	1	180	154
1	1	1	0	180	154
1	1	1	1	210	184

7. Results of optimization

By using Genetic algorithm and Matlab software, the solution shows that, we have to pump as much as possible of the water during the cheap time tariff. The schedule of pumps operation for next 24 hours is shown in figure (3). The variation of water level

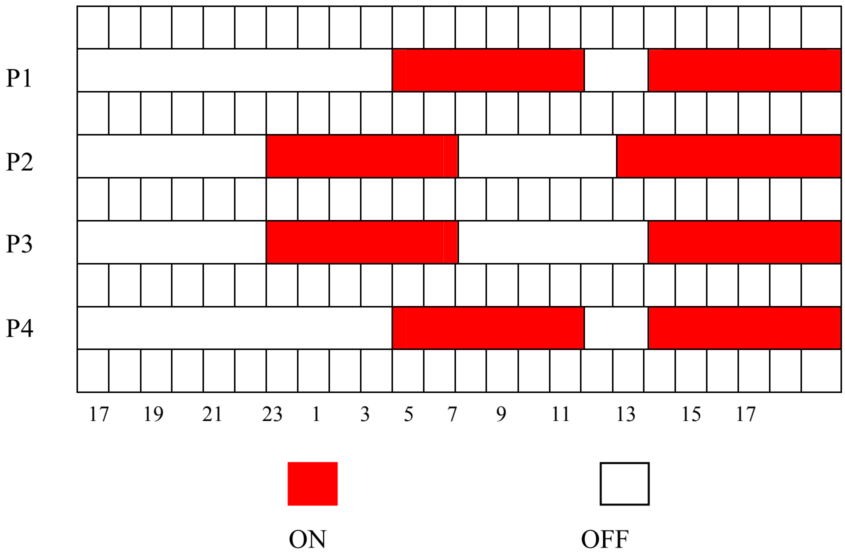

Figure (3): The schedule of pumps. operation

on the overhead tank for next 24 hours is shown in figure (4). There is no big level variation in the reservoir between the beginning and the end of the optimization period

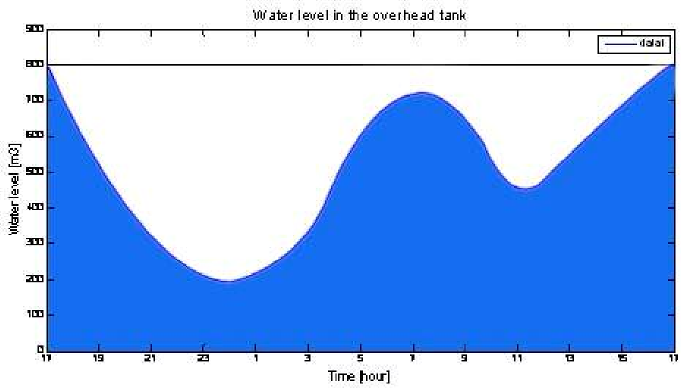

Fig (4): The variation of water level

8. Conclusion

Pump scheduling optimization with genetic algorithm is a highly effective method to reduce pumping costs without making changes to the actual infrastructure of the whole system. This paper presents the schedule of pumps operation that enable us to determining which pump will switched on or switched off. The water should be pumped as much as possible during the periods of low tariff and the periods of low electricity consumption. In this case, about two percent of energy can be saved and several millions of Syrian Pounds added up over the course of a year.

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