# PUMP SCHEDULING OPTIMIZATION FOR WATER SUPPLY SYSTEM USING ADAPTIVE WEIGHTED SUM GENETIC ALGORITHM

FOLORUNSO TALIHA ABIODUN

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Dedicated to the entire FOLORUNSO's

And to all those that believed in me

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# ABSTRACT

Water supply system has an inherently high operational cost. This is significantly due to the high amount of electric energy expended by the pumps of the system and the cost of their maintenance in cause of delivering water for the daily use by the consumers. Scheduling the operations of the pumps in the system ensures that the cost of energy consumed is minimized and also prevents the increased wear and tear in the pumps. Thus, creating an optimal schedule for the pumps is of paramount importance in order to save more electric cost which in turn leads to a reduced operational cost for the system. This work adopts the use of an Adaptive Weighted-sum Genetic Algorithm (AWGA), based on popular weighted sum approach Genetic Algorithm (GA) for multi-objective optimization problem. The AWGA weights multipliers of the individual cost functions are adaptively formed using the information of the fitness function on every generation of the GA process. This study adopts a water supply system consisting of 5 fixed speed pumps and a reservoir with the objective of minimizing the electric energy cost as well as the maintenance cost associated with the operating pumps subject to satisfaction of the maximum and minimum levels in the system reservoir. With the application of the AWGA a schedule that satisfies the demand requirement as well as the system requirement was obtained. Thereafter as a means for the validation and comparison of the results obtained, two other well known weighted sum GA approaches namely the Fixed Weighted-sum GA (FWGA) and Random Weighted-sum GA (RWGA) approaches were also simulated.. The results show that AWGA produces a schedule with a 16.2% reduction in terms of the fitness index parameter as compared 7.23% and 7.74% of the FWGA and RWGA respectively.

# ABSTRAK

Sistem bekalan air memerlukan kos pengoperasian yang tinggi. Ini adalah kerana jumlah tenaga elektrik yang digunakan oleh sistem pam dan kos penyelenggaraannya untuk kegunaan harian adalah tinggi. Penjadualan sistem pengoperasian pam bertujuan memastikan kos penggunaan tenaga dan pengurusan pam diminimumkan. Oleh sebab itu, keperluan untuk menghasilkan penjadualan yang optimum adalah amat penting untuk mengurangkan kos elektrik seterusnya secara tidak lagsung dapat mengurangkan kos pengoperasian sistem. Projek ini menggunakan algoritma Adaptasi Jumlah Wajaran Algoritma Genetik (AWGA) iaitu berdasarkan jumlah wajaran popular pendekatan Algoritma Genetic (GA) bagi masalah pengoptimuman pelbagai objektif. Berat pengganda fungsi kos individu adaptif AWGA dibentuk dengan menggunakan maklumat fungsi kecergasan pada setiap generasi proses GA. Satu sistem bekalan air yang terdiri daripada lima buah pam dengan kelajuan tetap beserta takungan air digunakan sebagai model kajian dengan objektif untuk meminimumkan kos tenaga elektrik. Dalam masa yang sama mengurangkan kos pengurusan pengoperasian pam, tertakluk kepada paras maksima dan minima takungan air. Dengan menggunakan aplikasi AWGA, satu jadual yang mampu memenuhi permintaan yang tinggi dapat dihasilkan. Seterusnya, bagi tujuan validasi dan perbandingan keputusan yang diperolehi, simulasi telah dilakukan menggunakan dua jenis wajaran GA yang popular iaitu Tetap Wajaran (FWGA) dan Pendekatan Wajaran Rawak (RWGA). Keputusan menunjukkan bahawa AWGA menghasilkan jadual dengan pengurangan sebanyak 16.2% dari segi parameter indeks kecergasan berbanding FWGA dan RWGA yang masing-masing adalah 7.23% dan 7.74%.

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| | | |
|---|---|---|
| AWGA | - | Adaptive Weighted-sum Genetic Algorithm |
| CNSGA | - | Controlled-elitist Non-dominated Sorting Genetic Algorithm |
| EA | - | Evolutionary Algorithm |
| EGA | - | Enhanced Genetic Algorithm |
| EP | - | Evolutionary Programming |
| ES | - | Evolutionary Strategies |
| FI | - | Fitness Index |
| FWGA | - | Fixed Weighted-sum Genetic Algorithm |
| GA | - | Genetic Algorithm |
| GSA | - | Genetic Simulated Annealing |
| MA | - | Memetic Algorithm |
| MOGA | - | Multi-Objective Genetic Algorithm |
| NPGA | - | Niched Pareto Genetic Algorithm |
| NSGA | - | Non-dominated Sorting Genetic Algorithm |
| OI | - | Optimal Index |
| PDI | - | Percentage Difference Index |
| PRV | - | Pressure Reduction Valve |
| PVC | - | Poly Vinyl Chloride |
| RWGA | - | Random Weighted-sum Genetic Algorithm |
| SA | - | Simulated Annealing |
| SPEA | - | Strength Pareto Evolutionary Algorithm |
| WSS | - | Water Supply System |

# LIST OF APPENDIX

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Water, being one of life's basic and essential commodity used by virtually all for daily activities ranging from domestic to industrial application. It is pertinent that this commodity is readily available to its consumers at the required time and in the desired quantity. To ensure this the water supply system must operate efficiently to not only satisfy the consumer demand but also operate at certain performance level to meet its operational objectives (Izquierdo, *et al*., 2009).

The conventional water supply system (WSS) is equipped with numerous energy consuming components, among which are the set of hydraulic pumps. These pumps most often of different sizes are used to convey water to and fro locations within the station. They are also used to deliver water into the elevated reservoir from where the consumers are supplied via fall of gravity. Due to the high energy requirement of these hydraulic pumps, the nature of the activity they perform and coupled with the electric energy tariff from the electrical utility company. These pumps tend to contribute a significantly large quota to energy consumption of the water system than any other component in the system. Consequently, accounting for the high operational cost associated with the water system. (Barán, *et al*., 2005; Mackle, *et al*., 1995; Sotelo, *et al*., 2002; Wang, *et al*., 2009).

There is a need for the optimization of the pump operations in order to minimize the high operating cost and also reduces the energy consumption associated with the system. Many researches as shown that this can be achieved through numerous methods amidst which is the creation of optimal schedule for the pump operation in the system. Pump scheduling has proven to be the most reliable and viable means of achieving reduced operational cost without effecting any infrastructural change to the design of the system (Abdelmeguid and Ulanicki, 2012; Wang, *et al*., 2009).

Various optimal control models have been developed to optimize the water supply system operation such as to minimize the cost of electric energy, maintenance, water treatment materials. Techniques such as the linear, non-linear, integer, dynamic and many other types of mathematical programming techniques has been applied to various model types of the water system (Abdelmeguid and Ulanicki, 2012; Gupta, *et al*., 1999; Hajji, *et al*., 2010). As the system requirement increases, there is an overall increase in the complexity and constraints of the system. Making it difficult to apply the aforementioned programming types due to increase in the number of mathematical computational requirement (Shu, *et al.*, 2010).

With advancement in the field of Evolutionary Algorithms, researchers have developed different algorithms as shown in Manuel, (2009) and Prasad, *et al* (2003) to optimize the multi-objective problem of creating an optimal pump schedule for the system. Most of which are based on the Pareto approach of Genetic Algorithm. Characteristically the Pareto approach Genetic Algorithm becomes inefficient if majority of the population becomes non-dominated, which may lead to extreme difficulty in the obtaining an optimum solution for the problem (Ismail, 2011).

In lieu of the above and the fact that there are no clear evidence that one algorithm can generally or completely outweigh the others totally with respect to its performance (Guo, *et al*., 2007). This study proposes the use of an Adaptive weight Genetic Algorithm to solve the problem creating optimum pump schedule for the water supply system. The objective is to minimize the electric energy and maintenance cost of the system. The Adaptive Weight Genetic Algorithm is based on the weighted sum approach of the Genetic Algorithm and it is designed such that the information of the fitness functions is used to determine and readjust the weights on every generation of the Genetic Algorithm process. The Adaptive weight Genetic Algorithm is comprehensive explained in Chapter 3.

## 1.2 Problem Statement

The pumps are the most important of all the components in the water supply system. They are categorized into high service and low service based on their position on the system layout. The low service pumps are set of pumps used for light operations within the system, while the high service pumps are used to deliver water into the storage facilities.

These high service pumps consumes significantly high amount of energy as a result of the nature of work they do, their power rating and coupled with the electric tariff than any other component of the water supply system (Barán, *et al*., 2005). According to Reynolds and Bunns (2010), these pumps accounts for about 43%of the entire energy of the station, which cumulatively results into a high amount of energy consumed. For instance in the UK the pumps of the water supply system consumes energy worth 700 million Euros annually (Wang, *et al*., 2009). In the US about 16% of the annual 75 billion KWh of electricity generated is been consumed by the pumps of the water supply facilities (Zheng Yi, 2007). In china about 30-50% of the total energy produced is been expended on the pumping station of the water system (Shu, *et al*., 2010).

Furthermore the operational cost of the water supply is not only been influenced by the energy consumed by the pumps but also on the cost associated with the maintenance of the pumps. As the pumps are turned on and off in cause of operation, wear and tear arises in them, which needs to be maintained. Generally the maintenance cost tend to increase with the increase in the number of times the pumps are turned on and off within the range of operation (Barán, *et al*., 2005; Mackle, *et al*., 1995; Manuel, 2009; Wang, *et al*., 2009).

Thus, in order to make the water supply system more economically reliable there is a need for the minimization of the operational cost of the system while still able to satisfy the demand requirement of the consumers. To achieve this the operations of the pumps is scheduled to allow for less pumps to be in operation while still been able to meet the demand requirement and without any physical infrastructural change to the already designed system .

## 1.3 Objectives

The objectives of this study are:

i. To study the operation of the water supply system, pump scheduling problem and to identify the objectives and constraint parameters for the optimization.
ii. To develop an optimized model for the scheduling of the pumps operations of the water supply system based on the Evolutionary Genetic Algorithm using Adaptive Weighted-sum approach.

## 1.4 Significance of study

Pump Schedule optimization is very essential and important to the operations and management of the water supply system. It helps in the minimization of the operational cost due to energy consumption up to about 5%-23% on a daily basis. This will in turn lead to significant reduction of the operational cost on monthly or annual basis (Hajji, *et al*., 2010; Mackle, *et al*., 1995; Shu Shihu, *et al*., 2010).

Furthermore, optimal pump schedule does not allow helps in the reduction of the energy consumed alone but also helps to conserves energy which also increases the system reliability.

## 1.5 Scope and Limitation

Pump schedule optimization of the Water Supply System is a complex problem and involves many underlying factors, consideration and constraints. Hence, in order to obtain an optimal model the following limitations and assumptions will be put into consideration;

i. The scope of this study is limited to only the water supply part of the Water supply and distribution system.
ii. This study will only consider fixed speed pumps with well defined parameters.
iii. The system is assumed to be able to satisfy the hydraulic as well as demand requirement.
iv. The system model is approximated using the mass model approach in order to reduce its complexity.
v. The input for the optimization include, the historical demand profile, the pump technical characteristic, the electric tariff plan and reservoir parameters.
vi. The adopted optimization technique will be based only on the use of weighted-sum Genetic Algorithm Approaches.

## 1.6 Report Outline

This study write up is divided into five chapters. In Chapter 1 the overview of the research study is presented. It introduces the pump scheduling as a problem to the water supply system and the need for its optimization. Also introduced are the various techniques that have been used in the past. Thereafter the objectives, scope and limitation of the study are presented.

In Chapter 2, a brief introduction into the constituent components of the water supply system and their operation are made. The pump schedule as a problem of the water supply system is treated in details as well as a review of the past works on the problem. Thereafter a review of the fundamentals of the Evolutionary Genetic Algorithm is presented. Also presented is a review of the various approaches of Genetic Algorithm for multi-objective optimization problems.

The proposed Multi-objective Genetic Algorithm approach 'Adaptive Weighted-sum Genetic Algorithm' is presented in Chapter 3. The principle and step for its implementation to the pump schedule problem is also presented therein. The modeling of the water supply system is also presented therein.

Chapter 4 presents and discusses the performance of the proposed approach to the problem of pump scheduling. First discusses the process of obtaining the parameters adopted for the algorithm and then the results of the multi-Objective optimization for the model under consideration. Also presented therein are the comparison results of the Adaptive Weighted-sum Genetic Algorithm with Fixed and the Random Weighted-sum approaches.

Chapter 5 concludes this write up. With a review of the objectives achieved so far in this work, suggestion for improvement of the adopted approach and also recommendation on future works.

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