APPLICATION OF COMPUTER BASED SIMULATION IN GAS NETWORK SYSTEM USING GRAPH THEORY ALGORITHMS AND NUMERICAL METHODS

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To my beloved father, mother, brothers and sister.

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ABSTRACT

The existing gas network software is highly depending on the Breadth First Search (BFS) and the Depth First Search (DFS) in performing gas network computation of any topology. This is causing the other graph theory algorithms remain least known to users. Apart from that, there are many numerical methods that can be used in performing the gas pipeline network analysis. Thus, the hypothesis of the method states that the Newton Gauss Elimination method is faster and more accurate than the Newton Gauss Seidel method. The objectives of this research are to determine the fastest graph theory algorithm, and to determine the fastest and the most accurate numerical method, in the development of gas network computer simulator. The developed computer simulator applies the Newton Nodal Method in performing the network analysis. Object oriented approach was used in designing the structure of the computer simulator. Two case studies and one extended case study were performed. Case study 1 and 2 involve 5 nodes low pressure gas pipeline network and 6 nodes medium pressure gas pipeline network respectively. The extended case study 1 involves 7 nodes high pressure gas pipeline network. The flow results from the computer simulator in the case study 1 and 2 were compared with GaPIS version 2.3. While in the extended case study, two flow equations for high pressure gas network system were compared for the accuracy. In conclusion, the BFS is the fastest graph theory with 5.37 milliseconds for case study 1, 5.48 milliseconds for case study 2 and 5.62 milliseconds for extended case study 1. The Newton Gauss Elimination is the fastest numerical method with 34.86 milliseconds for case study 1, 46.35 milliseconds for case study 2 and 50.26 milliseconds for extended case study 1. The combination of BFS and Newton Gauss Elimination gives the fastest speed, with 40.23 milliseconds in case study 1, 51.83 milliseconds in case study 2 and 55.87 milliseconds in extended case study 1. The average accuracies of both numerical methods for case study 1, case study 2 and extended case study 1 are 99.22%, 95.64% and 91.71% respectively.

ABSTRAK

Perisian komputer gas sekarang amat bergantung kepada *Breadth First Search (BFS)* dan *Depth First Search (DFS)* untuk mewakili sistem rangkaian gas dalam komputer. Ini menyebabkan teori graf yang lain kurang diketahui oleh pengguna. Di samping itu, terdapat pelbagai kaedah berangka boleh digunakan dalam menyelesaikan analisis rangkaian talian gas. Oleh itu, hipotesis tentang kaedah ini menyatakan bahawa *Newton Gauss Elimination* adalah lebih cepat dan lebih jitu daripada kaedah *Newton Gauss Seidel.* Objektif kajian ini adalah untuk menentukan teori graf yang paling pantas, dan menentukan kaedah berangka yang paling pantas dan paling jitu dalam membangunkan suatu perisian simulasi rangkaian gas. Perisian simulasi ini mengaplikasikan kaedah *Newton Nodal* dalam menyelesaikan analisis rangkaian. Pendekatan berorientasi objek telah digunakan dalam mereka struktur utama perisian simulasi. Dua kajian kes dan satu kajian kes tambahan telah dijalankan. Kajian kes 1 dan 2 masing-masing melibatkan 5 nod talian rangkaian gas bertekanan rendah dan 6 nod talian rangkaian gas bertekanan sederhana. Kajian kes tambahan 1 melibatkan 7 nod talian rangkaian gas bertekanan tinggi. Nilai aliran daripada perisian simulasi bagi kajian kes 1 dan 2 dibandingkan dengan keputusan daripada GaPIS versi 2.3. Manakala, untuk kajian kes tambahan, dua persamaan aliran bagi rangkaian gas bertekanan tinggi telah dibandingkan untuk menilai kejituannya. Pada kesimpulannya, *BFS* ialah teori graf yang terpantas, dengan 5.37 milisaat untuk kajian kes 1, 5.48 milisaat untuk kajian kes 2 dan 5.62 milisaat untuk kajian kes tambahan 1. *Newton Gauss Elimination* ialah kaedah berangka yang terpantas dengan 34.86 milisaat untuk kajian kes 1, 46.35 milisaat untuk kajian kes 2 and 50.26 milisaat untuk kajian kes tambahan 1. Penggabungan *BFS* dengan *Netwon Gauss Elimination* memberikan kelajuan terpantas, dengan 40.23 milisaat bagi kajian kes 1, 51.83 milisaat bagi kajian kes 2 and 55.87 milisaat bagi kajian kes tambahan 1. Kejituan purata bagi kedua-dua kaedah berangka untuk kajian kes 1, kajian kes 2 dan kajian kes tambahan 1 ialah 99.22%, 95.64 dan 91.71%.

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LIST OF ABBREVIATION

BFS	-	Breadth-First Search	
DFS	-	Depth-First Search	
MST	-	Minimum Spanning Tree	
path	-	Edge, branch, chord	
SCC	-	Strongly Connected Component	
vertex	-	Node, point	
E	-	Efficiency factor	
D	-	Internal pipe Diameter	mm
i	-	Initial vertex	
K	-	Constant flow equation	
L	-	Length	m
Q	-	Flow rate	m^3/hr
S	-	Specific gravity of gas	
T	-	Temperature	K
p_1	-	Pressure at sending node	bar/kPa
p_2	-	Pressure at receiving node	bar/kPa
P_n	-	Pressure at standard Temperature	kPa
T_n	-	Standard Temperature	K
$e_{a,i}$	-	Percentage approximation	

CHAPTER 1

INTRODUCTION

1.1 Introduction

Natural gas is one of the most important energy sources used in the world, besides oil and coal. Normally natural gas is supplied to users through natural gas pipeline system. Many pipeline systems are built throughout the world, from the gas reservoir to the end users, in order to support the highly increasing demand for natural gas. In America alone, from 1996 to 1998, at least 78 pipeline construction projects were completed adding approximately 11.7 billion cubic feet per day of capacity [1]. Meanwhile in Malaysia, as in January 2004, network of gas pipeline covering a total of 1,193.9 kilometres (831.7 kilometres completed) is constantly expanding to reach a larger population [2].

Natural gas pipeline systems become very complex as years pass by. The complexity of the gas pipeline systems makes people think ways to solve it. Program development is one of the solutions. With the help of computer program, people can gain information regarding the construction site and the pipeline chosen; design the gas pipeline systems and performing the network analysis before the construction of the actual pipeline systems.

This research is to develop a program that can help the users to design the pipeline system and solve the network analysis. Besides that, users can also know the pressure of certain point along the pipeline systems and load or flow rate of the pipe leg.

1.2 Problem Statement

Graph theory (graph theory algorithms) is a branch of mathematics concerned about how networks can be encoded and their properties measured[3]. This means in gas engineering term, graph theory is used to represent the gas network computation of any topology before the network analysis can be performed. Generally, graph theory algorithms are used in mathematic field.

The existing software (user friendly software) nowadays are highly depending on one or two graph theory algorithms, especially the Breadth First Search (BFS) and Depth First Search (DFS) in order to represent gas network computation of any topology, before working on a network calculation. So, lacks of studies on other graph theory algorithms, led to these graph theory algorithms remain unknown to users. These studies like the way of graph theory algorithms affect on network configuration, way of graph theory algorithms work on gas network system and so on. This research helps users to understand vividly about the graph theory algorithms, the way of graph theory algorithms work in the gas network system and compare all the graph theory algorithms in order to determine the fastest graph theory algorithms.

There are many numerical methods that can be used in solving the network analysis. The commonly used numerical methods are Newton Gauss Elimination method and Newton Gauss Seidel method. Thus, hypothesis of Newton Gauss Elimination method is faster than and more accurate than Newton Gauss Seidel method exists. This research helps users to understand both numerical methods and to determine the fastest and more accurate numerical method on steady state gas network system.

1.3 Objectives

The main objective of the research is to determine the fastest graph theory algorithms selected based on the computation time obtained in the development of gas network computer simulator.

In addition, the other objective of this research is to determine the fastest and the most accurate numerical methods in the development of gas network computer simulator. The numerical methods will be tested for their speed of execution (computation time) and checked their accuracy based on the flow results obtained from the computer simulator.

1.4 Scope of Study

In this research, a computer simulator for gas pipeline network system will be developed. This computer simulator can be used to simulate natural gas distribution network systems.

In order to ensure the success of the research, a right path is needed to be carried out step by step. The most important step is to choose the right computer program, which will be used to develop the computer simulator, and the programming language. MS Visual C++ is chosen due to its speed of execution, simple to use for programmers and developers and it is suitable for the creation of scientific, mathematical and statistical applications. C++ programming language is chosen because it is simple to understand and to code, and it is the programming language for MS Visual C++.

After choosing the right computer program and the programming language, studies of the existing software in the market will be done before the design of the structure of the gas network program. Object oriented approach will be used in the designing of the structure of the program.

Next, studies on different graph theory algorithms and numerical methods will be done due to different graph theory algorithms and numerical methods will be implemented into the computer simulator. There are five graph theory algorithms that will be studied, which are Breadth First Search (BFS), Depth First Search (DFS), Minimum Spanning Tree (MST), Strongly Connected Components (SCC) and Dijkstra's Minimum Path. Meanwhile, two numerical methods are studied, which are the Newton Gauss Elimination method and the Newton Gauss Seidel method.

The final step is to study the way of performing the network analysis. In performing the network analysis, Newton Nodal method in steady state condition and several of flow equations will be used. A network is in a steady state when the values of the quantities characterizing the flow of gas in the system are independent of time and the system is described by a set of nonlinear algebraic equations [4]. In steady state analysis, the pressure of the nodes and the flow rate in the pipes must satisfy the flow equations and the value of load node and source node must fulfil the two Kirchhoff's laws, which are the Kirchhoff's first law and Kirchhoff's second law (see Chapter 2).