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Simulation model for natural gas transmission pipeline network system

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ABSTRACT

This paper focuses on developing a simulation model for the analysis of transmission pipeline network system (TPNS) with detailed characteristics of compressor stations. Compressor station is the key element in the TPNS since it provides energy to keep the gas moving. The simulation model is used to create a system that simulates TPNS with different configurations to get pressure and flow parameters. The mathematical formulations for the TPNS simulation were derived from the principles of flow of fluid through pipe, mass balance and compressor characteristics. In order to determine the unknown pressure and flow parameters, a visual C++ code was developed based on Newton–Raphson solution technique. Using the parameters obtained, the model evaluates the energy consumption for various configurations in order to guide for the selection of optimal TPNS. Results from the evaluations of the model with the existing TPNS and comparison with the existing approaches showed that the developed simulation model enabled to determine the operational parameters with less than 10 iterations. Hence, the simulation model could assist in decisions regarding the design and operations of the TPNS.

1. Introduction

Natural gas is becoming one of the most widely used sources of energy in the world due to its environmental friendly characteristics. Usually, the location of natural gas resources and the place where the gas is needed for various applications are far apart. As a result, the gas has to be moved from deposit and production sites to consumers either by trucks in the form of liquefied natural gas (LNG) or through pipeline network systems. As reported in [1], short distances gas transportation by pipelines is more economical than LNG transportation. The LNG transportation incurs liquefaction costs irrespective of the distance over which it is moved. As a result, the development of transmission pipeline network system (TPNS) for natural gas is a key issue in order to satisfy the ever growing demand from the various customers [2].

When the gas moves by using the TPNS, the gas flows through pipes and various devices such as regulators, valves, and compressors. The pressure of the gas is reduced mainly due to friction with the wall of the pipe and heat transfer between the gas and the surroundings.

Compressor stations are usually installed to boost the pressure of the gas and keep the gas moving to the required destinations. It is estimated that 3–5% of the gas transported is consumed by the compressors in order to compensate for the lost pressure of the gas [3,4]. This is actually a huge amount of gas especially for the network transmitting large volume of gas. At the current price, this represents a significant amount of cost for the nation operating large pipeline network system. For instance, considering the US TPNS, Wu [5] indicated that a 1% improvement on the performance of the transmission pipeline network system could result a saving of 48.6 million dollars. Carter [6] also presented that the cost of natural gas burned to

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Nomenclature

A_E, A_H	constants for compressors equation
B_E, B_H	constants for compressors equation
C_E, C_H	constants for compressors equation
CS	compressor station
D	diameter
D_E, D_H	constants for compressors equation
D_i	customer located at i
D_{ij}	diameter of pipe joining node i and j
D_l	volumetric flow rate of load pipe$l$
E	pipeline efficiency
f	Darcy's friction factor
G	gas gravity
H	adiabatic head
HP	compression power
k	specific heat ratio
K_{ij}	pipe flow resistance
L	length
L_{ij}	length of pipe joining node i and j
LNG	liquefied natural gas
M	mass flow rate
MMSCMD	million metric standard cubic meters per day
MMSCFD	million standard cubic feet per day
n	rotational speed of the compressor
n_c	number of compressors
n_j	number of junctions
n_l	number of loops
n_p	number of pipes
N_P	number of unknown pressure variables
N_Q	number of unknown flow variables
n_s	number of compressor stations
N_{Total}	total number of unknown variables
P	pressure
P_s, P_d	suction, discharge pressure
P_n	standard pressure condition
q_j	volumetric flow rate of outgoing pipe j
Q	volumetric flow rate
Q_{Ci}	gas flow rate to customer i
Q_i	volumetric flow rate through pipe i
Q_n	volumetric flow at standard conditions
R	gas constant
t	number of incoming pipe to a node
T	temperature of gas
T_S	suction temperature
T_n	standard temperature conditions
TPNS	transmission pipeline network system
u	number of outgoing pipes from a node
w	number of load pipes from a node
X	vector representing unknown variables
Z	gas compressibility
Z_1, Z_2	suction, discharge side compressibility

Subscripts

d	discharge side of the compressor
E	efficiency
H	head
i, j	upstream node, downstream node
s	suction side of the compressor

Greek symbols

η_a	adiabatic efficiency
γ	the ratio of specific heat