Recovering Lost Power in Natural Gas Pressure Reduction Stations using Hybrid Turbo Expander and Fuel Cell Systems

By

Shaimaa Tarek Soltan

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in

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Title of Thesis:

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Key Words:
Fuel Cell Systems, Hybrid Turbo Expander, Net Present Value, Pressure Reduction Stations, Throttling Valves

Summary:

The main goal of this thesis is to investigate the performance of the hybrid turbo expander and molten carbonate fuel cell system (HTEMCFC) for power recovery at natural gas pressure reduction stations. Simulations were created to predict the performance of various system configurations.

Acknowledgments

It is my honor to extend my thanks and gratitude to my supervisors **Prof.Dr. Mohamed Salah Elsobki** and **Dr. Moustafa Elshahed** for their excellent thesis supervision.The success, which I achieved, is due to my supervisors because they were always supporting me. My family and friends also give me a great hope to end my work and reach the success. They were always supporting me. I am grateful to all of them.

Dedication

I dedicate this thesis to my parents, my sisters and my best friends.

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Nomenclature

P_1	System inlet pressure (kPa)
P_2	System outlet pressure (kPa)
h_i	System inlet enthalpy (kJ/kg)
h_1	Preheat enthalpy (kJ/kg)
h_2	Turbo expander outlet enthalpy (kJ/kg)
h_{2s}	Turbo expander isentropic outlet enthalpy (kJ/kg)
h_{2Valve}	Expansion valve outlet enthalpy (kJ/kg)
s_1	Turbo expander inlet entropy (kJ/kg*K)
T_i	System inlet temperature (°C)
T_1	Preheat temperature (°C)
T_2	Turbo expander outlet temperature (°C)
T_{2Valve}	Expansion valve outlet temperature (°C)
T_3	System outlet temperature (°C)
P_{STD}	Standard Pressure (kPa)
T_{STD}	Standard Temperature (°C)
$\dot{m}$	System flow rate (kg/s)
$\dot{m}_{Turbo}$	Turbo expander flow rate (kg/s)
$\dot{m}_{FC}$	Fuel flow to fuel cell (kg/s)
$\dot{m}_{BoilerFuel}$	Fuel flow to boiler (kg/s)
$\dot{m}_{Fuel}$	Total fuel flow (kg/s)
$\dot{Q}$	Preheating requirements (kW)
$\dot{Q}_{FC}$	Fuel Cell heat rate (kW)
$\dot{Q}_B$	Boiler heat rate (kW)
$\dot{W}$	Turbo expander Power (kW)
HHV	Higher heating value (kJ/kg)
$P_{electrical}$	Electrical power from generator (kW)
$P_{fuelcell}$	Electrical power from fuel cell (kW)
η_B	Boiler Efficiency
$\eta_{turbine}$	Turbo expander efficiency
η_{design}	Turbo expander design efficiency
$\eta_{gearbox}$	Gearbox efficiency
$\eta_{generator}$	Generator efficiency
η_{system}	System efficiency

Abstract

As the world is seeking to use a clean fuel to power up engines, natural gas is one of the most important candidates in this area. In order to use natural gas for residential and industrial purposes, the gas pressure needs to be reduced to pressure that is more convenient for these purposes using Pressure Reduction Stations (PRS).

The ordinary PRS using throttling valves to achieve the required pressure drop. There is energy contained in the pressure of the high-pressure gas in the form of enthalpy. The conventional pressure reduction devices used in pressure reduction stations waste this energy.

In order to save this energy a turbo expander is used in the PRS which is used to drop the pressure of the gas and drives a generator to produce electricity but this process causes a larger temperature drop. This temperature drop could cause ethane in the gas to condense after expansion or frost problems surrounding the pipe system. To avoid this cooling problem the gas needs to be preheated. Currently, the gas-fired boiler is used and the hybrid turbo expander and fuel cell system is a new approach to this problem. A fuel cell is used to preheat the gas before it enters the turbo expander, and it helps to provide a low range of electrical power.

In this study, five system configurations were simulated using the Engineering Equation Solver (EES) in order to find the most efficient system to operate in El-Mansoura PRS.

After simulating the systems, it was found that the most efficient systems was the Hybrid single turbo expander and fuel cell system and it was necessary to find the optimal sizing for turbo expander and fuel cell.

After investigating some of the available range of turbo expander design flow and fuel cell power it was found that the optimal efficiency for El-Mansoura PRS was achieved when using a 15000 m3/hr single turbo a PRS expander with a 300 kW fuel cell power.

Chapter 1 : Introduction

1.1. Background

Natural gas is a widely used fossil fuel throughout the world. Applications, where natural gas is used, include power generation, space heating, water heating, cooking and many industrial processes. It is one of the cleanest burning fossil fuels in use today.

Most Egyptian production of natural gas is used to satisfy domestic demand; Egypt produced 2.2 Trillion Cubic Feet of natural gas in 2011, where 1.8 Trillion Cubic Feet was used for domestic consumption and the remaining was exported. The power generation sector is the one which consumes most of the local production.

The domestic consumption in Egypt has increased by an annual average of 11 percent from 2001 to 2011. Natural gas production rapidly increased for most of that period as well, but after 2009 natural gas production began to decay because of the gas fields output decline. As a result, the Egyptian exports have also decayed. The government may start to import natural gas for the first time, to satisfy rising domestic demand and continue to export natural gas to global markets.

Natural gas is transported in pipelines at high pressure, which is called the transmission grid. This transmission grid operates at high pressures while local distribution grid operates at low pressures, as it is more appropriate for usage. This pressure drop is achieved by "Pressure reduction stations" which are located between the high-pressure transmission network and low-pressure distribution network. At these stations, the pressure is dropped to the appropriate pressure for the low-pressure network.

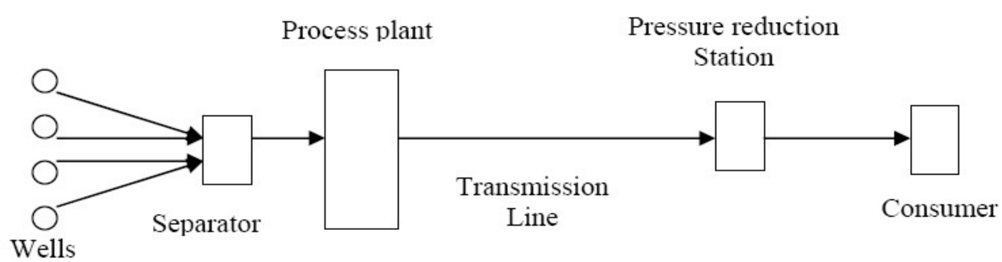

Fig. 1.1 Simplified Schematic of Natural Gas Supply Chain [2]

There is energy contained in the pressure of the high-pressure gas in the form of enthalpy. The conventional pressure reduction devices used in pressure reduction stations waste this energy.

The fact that there is an energy crisis nowadays creates a huge need to reduce the energy consumption and to restore energy from any possible source. One source is the pressure difference in the pressure reduction stations, and that energy could be restored by dropping the pressure using turbo expander, which drives generators to produce electricity. In this process, turbo expanders work in parallel with throttling valves. The power output can be between hundreds of kW to several MW.

Turbo expander systems have been in use for many years for a variety of power recovery applications. Natural gas pressure reduction turbo expanders are currently in use in Europe and to some extent in North America for power recovery. At some natural gas pressure regulating stations in Europe and a few in the United States, expansion turbines are being used for power generation.

In order to produce the required pressure drop, it is important to maintain the flow through the turbo expander within its operating conditions and maintain adequate power generation. A challenge associated with the operation of this type of system would be fluctuating natural gas flows through the regulating station. The turbo expander has a set operation range and can only generate power within that range. Effective turbo expander sizing is therefore very important in order to recover the maximum amount of power.

Cooling effects associated with the expansion process can cause problems on the low-pressure side. The temperature drop could cause ethane in the gas to condense after expansion or frost problems surrounding the pipe system. To avoid this cooling problem the gas needs to be preheated. Currently, the gas-fired boiler is used and the hybrid turbo expander and fuel cell system is a new approach to this problem. A fuel cell is used to preheat the gas before it enters the turbo expander, and it helps to provide a low range of electrical power.

Enbridge Inc. and Fuel Cell Energy developed this hybrid system of turbo expander and fuel cell (HTEMCFC), and this system is now operational in Toronto. In addition, factors affecting the scalability of such a system were investigated in this study.

As a result of this investigation, the pressure ratio, flow rate, and temperature were found to be important factors which affect the performance of the system.

Data from El-Mansoura Pressure Reduction Station was used to perform a simulation of a proposed natural gas expansion station in the city. The data used in this simulation was collected over a year.

1.2. Research objectives

The main objective of this research is to investigate the factors affecting the overall performance of hybrid turbo expander and fuel cell systems for natural gas pressure reduction and recovering electrical power in the process. In particular, this study focuses on investigating power outputs, fuel requirements and efficiencies of systems under typical gas flow variations. An important objective of this research is to study the system sizing criteria to maximize power output and revenue for this type of system.