POWER TO GAS: DESIGNING A PILOT PLANT FOR USING SOLAR ENERGY TO PRODUCE FUEL

By

Mahmoud Mohamed Salah Elden

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
Interdisciplinary MSc. - Petroleum and Natural Gas Technology

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Key Words:
Hydrogen production, photovoltaic system, water alkaline

Summary:

Power to gas (PTG) is the process of converting surplus power into another form of energy. Power-to-gas is the functional description of the conversion of electrical power into a gaseous energy carrier like e.g. hydrogen or methane. This technological concept considered as an interesting tool in the energy transition. The most common form is the hydrogen gas. Hydrogen considered as an energy carrier that produced by several methods. The most common method is the steam gas reforming process that uses natural gas as a feedstock to produce hydrogen. The other method is the water electrolysis process, which is the decomposition of water molecules into hydrogen and oxygen using solar energy. The produced hydrogen injected directly to the natural gas grid with specific limit in transmission or in distribution pipelines. As a result, power-to-gas enables the share of renewables in the energy mix to increase, making this innovation an important topic in achieving a carbon-neutral gas supply in 2050.

Disclaimer

I hereby declare that this thesis is my own original work and that not part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

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Nomenclature

ATR	: Auto-thermal reforming
AWE	: Alkaline water electrolysis
Boe	: Barrel of oil equivalent
Cp	: Specific heat capacity at constant pressure [kJ/kg.K]
Cv	: Specific heat capacity at constant volume [kJ/kg.K]
CCGT	: Combined-cycle gas turbine
CHP	: Combined heat and power
d	: Relative density compared to air [-]
FCV	: Fuel cell vehicle
GHG	: Greenhouse gases
HHV	: Higher heating value [MJ/Nm³]
i	: Interest or discount rate [%]
IGCC	: Integrated gasification combined cycle
K	: Compressibility factor [-]
n	: Lifetime [years]
NG	: Natural gas
PE	: Polyethylene
PV	: Photovoltaic
PTG	: Power to gas
PEM	: Proton exchange membrane
PEMFC	: Polymer electrolyte membrane fuel cell
Q	: Normal flow rate [Nm³/h]
R	: Universal gas constant = 8.314 J/mol.K
RES	: Renewable energy sources
SI	: Spark ignition
SMR	: Steam methane reforming
SOE	: Solid oxide electrolyzer
WI	: Wobbe index, based on the higher heating value [MJ/Nm³]
Z	: Compressibility factor
Kwh/m^3	: Kilowatt hour/m^3
MM Toe	: Million-ton oil equivalent
^{o}E	: Cell Potential
MPPT	: Maximum power point tracker
Mz	: Methane number
MW	:Mega watt
GJ	:Giga joule

Abstract

Balancing between the energy demand and supply is very important for the economy, as well as social development of a country. The country is facing from unbalance of energy mix. Therefore, the government has confirmed to diversify the sources of energy to overcome this issue.

Renewables energy is energy derived from an infinite source, it is very important to choose the power source you use. Many factors, such non-toxicity, cost, stability, efficiency and environmental effects should be taking into consideration. Many industries around the world still rely on fossil fuels. There is no doubt that these types of fuel are extremely effective in terms of the quality of energy production, but fossil fuels will be exhaust in one day and industries must be transform into renewable sources as soon as possible. Solar energy considered as a suitable energy source, as Egypt lies in the bright belt and has abundance amount of sunshine consistently. Energy is the main factor of industry, as the population of the world increases and people hope for a higher standard of living, the amount of energy is increasing to meet the necessities.

Blending of hydrogen with the natural gas network proposed as a method for increasing the utilization of renewable energy systems, for example, photovoltaic cells. Hydrogen injection will be accepted with a specific limit without increasing the risk associated with natural gas mixed in end-use devices, durability and integrity of the current natural gas infrastructure.

In this work, an alkaline electrolysis system designed and constructed to produce hydrogen using photovoltaic (PV) module as a source of power. The system installed, tested and modeled under the weather conditions in Cairo. In addition, the system designed in numerical simulated and validated through empirical data using Excel spreadsheet. The simulation results verified with the corresponding measured data under the same conditions of weather of Egypt.

The goal of this work, study the ability of hydrogen production by coupling of a PV array with alkaline water electrolyzer directly, by matching the current and the voltage of two components.

The variation of the monthly average maximum output energy of PV modules mounted facing south with 30˚ tilt angle, indicates that, the photovoltaic module current, is directly affected by the solar radiation intensity. The increasing of the electrolyzer current increases the hydrogen production flow rate in the proposed small scale system, that has electrolyzer box of 4500 cm^3, containing 80%, electrolyte solution by volume, with electrodes of 2 cm^2 cross section area.

It is predicted that, the annual hydrogen flow rate strongly affected by the climatic conditions of solar radiation and ambient temperature. The hydrogen flow rate ranges from 16 ml/min in winter months to about 26 ml/min as maximum value for summer months. For the proposed electrolyzer dimensions, an average 322 liters of hydrogen monthly produced. The electrolyzer efficiency is almost (52-64%). With the present knowledge of the hydrogen production from electrolyzer, the production cost calculations were prepared based on a 2 MW electrolyzer plant, the hydrogen production cost ranges between 4.9 – 5.3 \$/kg H_2, which equal to 0.44-0.47 \$/m^3 H_2. It is clear that the power price is an essential parameter for hydrogen production.

Chapter 1 : Introduction

There is public awareness of the negative social and environmental impact of the use of traditional energy sources, and the non-renewable energy sources (fossil fuels) at its highest level at all. The world reserve of oil and natural gas may stay to an additional 40 years just at the present utilization rate

Egypt primary energy consumption is about 91.6 MMtoe in 2017, 96% of total primary energy consumption in Egypt is from fossil fuels, while some energy comes from hydropower. The government aims to diversify the energy mix in favor of renewable energy resources and set a target to achieve 20% of generated electricity from renewable energy by 2020. [1]

Table 1.1: Egypt's primary energy consumption

Year	1995	2000	2005	2010	2015	2016	2017
MMtoe	37.3	48.4	60.5	78.4	84.4	88.2	91.6

Table 1.2: Egypt's primary energy consumption by fuel 2016-2017

MMtoe	Oil	Natural Gas	Coal	Hydro-Electric	Renewables	Total
2016	42	42.4	0.2	3	0.6	88.2
2017	39.7	48.1	0.2	3	0.6	91.6

After suffering a series of shortages in domestic energy supply, declined investment inflows and escalation of political conflict just a few years ago, the situation has been changed after several recent gas finds, including the massive "Zohr" discovery, with the major finds in the Mediterranean Sea and North Delta.

From the previous discussion, it is clear that there is a need for a new energy supplies and upgrade the energy infrastructure in order to be compatible with the growth of demands on fuels requirements for transportation and electricity sectors.

Egypt must expand its energy sources by take advantage of their renewable energy resources, particularly wind, because of its financial potential and solar energy, as illustrated by solar atlas and solar power observations in Egypt. Therefore, it was necessary to look for other sources of energy to use in addition to oil and gas to be a combination of energy balance and thus exploit it in maximizing the capacities of natural gas.

Renewable energy sources (RES) are resources for the continuous natural process on the planet, resources recharged normally and within the future nearly endless. Egypt is one of the solar belt countries that appreciate high solar energy. Therefore,