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Potential Swing to Natural Gas-Powered Electricity Generation

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Abstract

Natural gas (NG) is a light gas, known also as methane due to high percentage of the gaseous compound methane (CH_4). Percentage of methane in natural gas varies country-wise. This gas is an alternative source of electricity generation. This paper aims to explore the present status of natural gas in the energy sector; more specifically, its application in the power grid. Findings shows that natural gas is gaining high patronage with time; and most countries are turning to gas mainly because it is cheap and a reliable source of electricity generation. So, in order to solve possible problems associated with gas utilization in this area, authors in the field of electricity and chemical engineering have written and propose models that are effective to solve challenges (peculiar to a particular country) as well as those that can be applied in most situations. NG is presumed to replace all other sources of power utilization in the near future. Presently, there is a possibility of building gas-powered plants in the Northern part of Nigeria, especially the Borno State capital, Maiduguri that was cut-off from the nation's grid by terrorist.

Keywords: Natural gas; Electricity generation; Renewable Energy; Programming models; Gas Consumption.

1. Introduction

Natural gas is non-toxic, odorless and colorless gas with a gross heating value ranging from 36-40.2 MJ/m^3 dry basis [1]. The presents of methane in natural gas makes it combustible [2], with a characteristic clear blue flame.

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It has an ignition temperature of 564℃, flame velocity of 0.36 m/s, specific gravity ranging from 0.57-0.62 and wobble number in the range of 47.5-51.5 MJ/m^3 [3]. Natural gas composed commonly of methane, ethane, propane, butane, carbon dioxide, oxygen, nitrogen, hydrogen sulphide and traces of rare gases. Different countries have different compositions of these gaseous components in their NG. Denys and Vries (2013) presents the compositions of NG from 17 different oil producing countries across the world. This compositions can be summarized in Table 1:

Table 1: Composition of Typical Natural Gas [2-6]

Compound	**Symbol**	**Composition (mole %)**
Methane	CH_4	60-96
Ethane	C_2H_6	0-20
Propane	C_3H_8	0-20
Butane	C_4H_{10}	0-20
Carbon dioxide	CO_2	0-8
Oxygen	O_2	0-0.2
Nitrogen	N_2	0-5
Hydrogen sulphide	H_2S	0-5
Rare gases	Ar, Ne, He	0-2

Gas plays a particularly prominent role in heat generation such as for the domestic, public and industrial sectors [7]. Apart from heat and electricity generation, NG is used in air conditioning, cooking, transportation fuel, water heating, clothes drying, lighting fire and manufacturing chemicals (such as acetic acid, ethane, ammonia, methanol, butane, propane etc). As seen in Fig. 1 and 3, United States is the largest consumer of NG (around 27,243,858,000 MMcf-million cubic feet), followed by Russia and China for wide ranging applications [8]. South Korea (in green pie sector) and Argentina plus other seven countries utilizes only around 2% of the 20 countries reported by Worldometer as depicted in Fig. 3. Hultman and his colleagues (2011) noted in their collective work on the impact of greenhouse gas from unconventional gas for electricity generation that, extracting natural gas from unconventional sources such as shales or tight sands is becoming prominent. Reason being that gas produced from unconventional wells has roughly the same methane content as that produced from conventional wells and therefore combustion can be assumed to yield the same climate effect. Currently, electricity is produced not only from coal and nuclear power but also from Renewable Energy Sources (RES) such as solar, wind, hydropower and geothermal. For example, electricity from RES already in 2015 saved the EU several billion euros in fossil fuel imports [7]. In Malaysia, Abdul Latif and his colleagues (2021) acknowledged that electricity is still dominated by fossil fuels; and environmental issues accompanying this is global warming as it increases the concentration of CO_2 in the air. McQueen and his colleagues (2021) also maintained that removing CO_2 from the air with chemicals (Direct Air Capture, DAC) requires a significant amount of energy. Coal and natural gas are depletable fossil fuels commonly used to generate electricity, each with operational advantages and environmental impacts [9]. However, methane is a more potent greenhouse gas than carbon dioxide, meaning even small leaks can greatly impact the climate attractiveness of the use of natural gas compared to coal in the power sector [10].

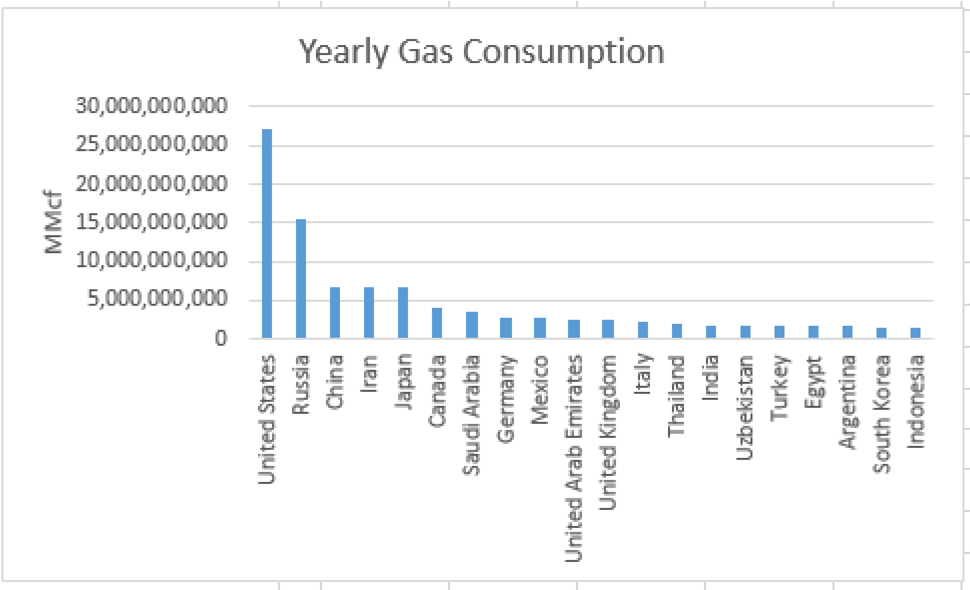

Figure 1: Annual Gas Consumption by Country [6], [8]

The use of NG in developing countries is still less, with an average of 20% of their energy matrix [11]. Residential demand of NG for electricity generation forms the basis of knowing the stress on the gas distribution networks, as well as the electric grid and can help to stabilize local energy markets. This was however investigated by Speakie and his colleagues (2020) for residential buildings in the United States. Natural gas is increasingly preferred as a choice of fuel for electricity generation globally resulting in electricity systems whose reliability is progressively dependent on that of the natural gas transportation system [12]. Availability of relatively cheap NG supply, environmentally responsible regulations, and the improved efficiencies, competitive investment cost, relatively short ramp rates, modularity and scalability of NG-fuel generators is expected to drive the growth of electricity generation from NG by 110% from 4.8 trillion kWh to 10.1 trillion kWh from 2012 to 2040 [13]. Alternatively, liquefied natural gas (LNG) is produced by liquefaction of natural gas in cryogenic conditions. In process of regasification the large part of energy stored in LNG may be recovered and used for electricity generation [14].

2. Gas for Electricity Generation by Country

Most importantly, every country have their peculiarity with respect to gas-use for power generation. Nigeria is capable of generating thousands of megawatts of electricity from gas power stations in Nigeria. Based on the most recent count, there are 24 power stations in the Southern part of Nigeria, capable of generating 12,654 MW of electricity from NG. Because most of the gas produced is exported, it leaves the Nigerian power sector with reduced amount of gas to produce electricity [15]. This challenges was also acknowledged by Murtala and his colleagues (2013). Therefore, Nigeria is ranked as the 38th country in world’s domestic utilization of the gas, using only approximately 670, 000, 000 MMcf [8]. Based on the country’s new target and policies in the power sector, the Northern part of Nigeria is seen as the next ground to set up gas-powered stations in Nigeria. Matar & Shabaneh (2020) sees the need to store NG as they hypothesize that NG storage infrastructure in a country like Saudi Arabia will provide power plants with NG during peak power load periods. They also emphasize that industrial use of natural gas would limit its availability for the power sector. China has been the world’s third largest consumer of NG, and it has been in the rapid-growth stage [16]. Zhongyuan and his colleagues (2018), presumed that: ‘gas consumed for power generation will increase to about 195 billion m^3 (in 2030, just 26% of China’s total consumption), an annual increase rate of 10% from 2020-2030’. Readers can also find ‘Life cycle analysis of coal-based synthetic natural gas for heat supply and electricity generation in China’, authored by Gao and his colleagues (2018) interesting. Currently, the Surgut-2 power plant in Russia (Fig. 2) is the world’s largest gas power plant.

Figure 2: Natural Gas Power Plant in Russia [17]

Nuclear plants age, and when they do, physical properties of their useful materials changes prompting shut down or decommissioning. Some of these properties are thermal embrittlement, creep, fatigue, corrosion, conductivity and irradiation embrittlement. Countries like the United States (US) utilizing nuclear powered plant, need to plan for inevitable challenges that they most to face in the future. As a result, the unpredictability of NG usage for generating electricity in the US was investigated by Tsai and his colleagues (2017), in addition to fluctuating natural gas prices and retirement of nuclear plants. The long-term modeling suggests that, NG usage for power generation in year 2030 could range from 8.7 to 15.1 trillion cubic feet, with the price of natural gas appearing to be the most important factor [18]. Approximately 61.3% of all utility-produced electricity in Turkey is from NG; the largest in the country according to Tsai and his colleagues (2017).

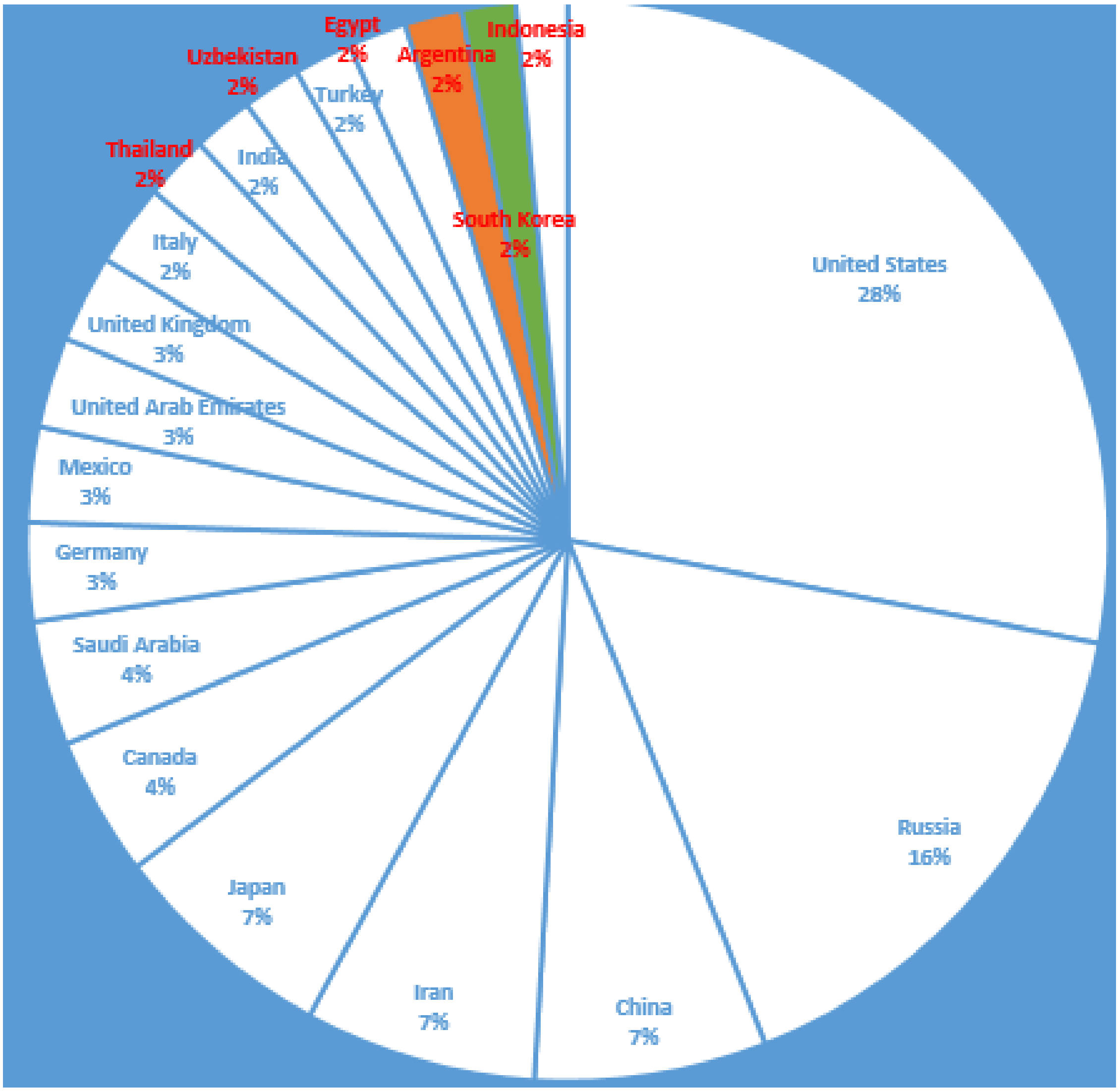

Figure 3: Percentage Gas Consumption of Some Countries

2.1. Associated Models

Menezes and his colleagues (2020) optimization research paper as regards gas-powered thermopower plants was proposed to be applied in various countries. Models written and proposed by several authors specifically address some challenges in electricity generation from NG (in their various countries) and other sources are tabulated (see Table 2):

Table 2: Models on Electricity Generation

Model Description	Reference
The cost of installing gas pipelines, compressors and gas storage cylinders is high. Therefore, a chance constrained programming model (CCPM) was developed to minimize the investment cost for the Belgian high-calorific gas network.	[19]
Two agent-based models of energy markets are considered: one modelling the market for natural gas and the other of the electricity market incorporating a CO_2 market. Both models presented here are based on a shared ontology of socio-technical systems and they share a number of	[31]

building blocks, but domain specific assumptions and additions had to be made in each case.	
Work dealing with implementing, comparing and optimizing natural gas and electricity networks by developing a deterministic and stochastic models. Furthermore, the value of flexibility options (i.e., electricity storage systems) in dealing with uncertainty was quantified.	[20]
Power-to-gas and battery as well as carbon intensities are evaluated using carbon emission flow (CEF) model that also track emissions. Carbon emission and intensity is reduced as showcased by the simulation result.	[28]
Natural gas system is modeled and its security constraints are integrated into the economic dispatch (ED) model. The objective function for ED model is to minimize power system operating costs considering coal-fired generating units operating costs and natural gas-fired generating units (NGFGU) operating costs respectively.	[22]
Developing a mixed-integer linear programming (MILP) model that focuses on expansion co-planning studies of natural gas and electricity distribution systems to guarantee the finite convergence to optimality. Mathematical model of expansion studies associated with the natural gas, electricity and energy hubs (EHs) are extracted. The optimization models of these three expansion studies incorporate investment and operation costs.	[26]
A two-stage scenario-based stochastic model aiming to minimize total operational cost considering wind energy, electrical load, and real-time power price uncertainties. The AC-power flow and Weymouth equation are extended to describe power and gas flow in feeders and gas pipelines, respectively. The proposed model is tested on the integrated energy system and consists of a 33-bus electrical network and a 6-node gas grid with multiple interconnected energy hubs, where the numerical results reveal the effectiveness of the proposed model.	[24]
Markov chain based modelling and prediction of natural gas allocation structure in Pakistan followed by its validation through error evaluation. Structural prediction using classical Chapman-Kolmogorov method and varying-order polynomial regression in the historical transition matrices are presented.	[27]
A deterministic coordinated model for the secure and optimal operation of integrated natural gas and electricity transmission networks by taking into account the N-1 contingency analysis on both networks. In order to reduce the computational burden and time, an iterative algorithm is proposed to select the critical cases and neglect other contingencies, which do not have a significant impact on the energy system.	[23]
In integrated electricity and natural gas systems (IEGSs) operations, the nonlinearity of the natural gas system brings challenges to the system operators. The IEGSs optimal power flow (OPF) model is proposed that includes the line pack of the gas system via linear approximation.	[29]
The impact of different levels of natural gas resilience on the resilience of electric power systems was studied. A novel mixed integer programming (MIP) model is presented that incorporates the dependency of the power system on natural gas system supply. A modified IEEE 118-bus with 12 combined-cycle units is presented for analyzing the gas/electric interdependency	[30]
A Chance constrained and reliability programming optimization model was proposed for solving the long-term integrated planning problem and their performance was compared by illustrating them on the standard IEEE 30 bus test system superimposed on the Belgian high calorific gas network.	[12]
The author made assumptions leading to the derivation of stochastic nonsmooth envelopment of data (StoNED) for both scale elasticity and efficiency satisfying microeconomic properties estimators. Results from the parametric StoNED, indicate that on average plants operate under constant to slightly decreasing returns-to-scale, and scale inefficiency is found to be overall rather than low.	[21]
The objective is to minimize the operation cost of the electricity and natural gas networks considering the price of the natural gas supply. Benders decomposition is used to solve the formulated problem. It is shown that leveraging the stored gas in the natural gas pipelines would further reduce the total operation cost.	[25]

Table 2 presented fourteen models proposed by various researchers regarding electricity generation from NG. These are however, not the only models out there, more are out there which can be tested and applied. Some models are done for specific countries. Researchers are encourage to replicate it for their host countries and compare test results for analysis. Software development such as the one developed by Ismail and his colleagues

(2018) to compute gas turbine performance is an example of programming inputs that will tremendously help engineers to either build or operate gas plants; a semblance to a calculator on cubic equations of state written by Abubakar and his colleagues (2021) to compute molar volume. Furthermore, artificial neural network has been applied in the oil sector [32] as well as in the prediction of biogas yield from waste biomass. It is therefore important for researchers to study areas neural network analysis is beneficial to gas-powered electricity generation. This, together with linear programming can be demonstrated to optimize the electric load, shortest distribution lines, electrical power grid design [33] and cost maximization. Kharbach and his colleagues (2010), Mukherjee & Rao (2015), as well as Dias & Jorge (2016), expounded their opinion on cost, imports and taxes associated with generation of electricity from natural gas.

3. Conclusion

As fossil fuels emits greenhouse gases, more promising electricity generation technology to solve the problem of intermittency of RES such as gas-fired power plants are encouraged. Gas-fired power plants are important due to high efficiency, low greenhouse gas emissions, low cost of investment and flexible performance. Various model to help solve problem arising from the use of NG power generation were proposed by different authors to address, supply, cost savings, demand and other important factors. The work is limited to a study of the shift from other electricity sources to NG in the power sector with some few models proposed for optimization of the system. It can be resolved that, global electricity generation from natural gas is expected to continue in an upward trend in the coming years thereby increasing the interdependency between the electricity and the NG transportation system.

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