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Original article

Techno-economic assessments of advanced Combined Cycle Gas Turbine (CCGT) technology for the new electricity market in the United Arab Emirates

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ABSTRACT

In this study, a dynamic cost model was constructed to compare the Levelised Costs of Electricity (LCOE) for advanced Combined Cycle Gas Turbine (CCGT) technology in comparison to traditional CCGT technology. The key technical and economic factors that affected the competitiveness of these CCGT units were evaluated. The results showed that advanced H-class CCGT technology has the lowest LCOE for the base case scenario at 4.93 US cents/kW h versus 5.32 and 5.71 US cents/kW h for F- and E-class technologies respectively. It is evident that the more advanced CCGT technology matches the major market drivers for the United Arab Emirates (UAE) energy transition, namely; competitive lifecycle costs, high thermal efficiencies which reduce fuel costs and limit CO_2 emissions and a high operational flexibility. The LCOE model outputs summarise the overall financial competitiveness of the different CCGT technologies for the UAE up to the year 2030 considering the future power generation demand profile. There are no H-class gas turbines installed in the UAE and this was one of the drivers behind this paper to show the benefits of the latest advanced CCGT technology. The study conveniently facilitates future discussions on the opportunities and challenges of the UAE's energy transition for developers, electricity suppliers and national policy makers.

Introduction

Electricity demand and supply growth has several drivers. These can include economic growth, fuel prices, peak loads and seasonal variances, energy intensity, industry structure, renewable policies and availability and security of supply [32]. In the United Arab Emirates (UAE), the annual energy demand has grown steadily over the last six years at an average of 4% [39] and the peak energy demand will double from 23 GW in 2010 to 52 GW by 2030 [27].

The electricity demand and supply growth in the UAE are mainly due to its expanding economy and population, the hot desert environment, energy intensive industries and high personal incomes that translate into high levels of energy consumption [37]. The high national energy demand is leading to two significant issues for the country; firstly the UAE has one of the highest carbon footprints in the world [18] and second, the depletion of its natural gas reserves, on which it is almost entirely dependent on for electricity generation, is leading to an enormous energy shortage [12]. Both of these issues highlight the need for a sustainable energy transition strategy to reduce the environmental impact of electricity generation and to secure reliable and sustainable energy sources. In this regard, the UAE, despite having some of the largest reserves of oil and gas in the world, is currently diversifying its energy mix away from hydrocarbon-based electricity generation and is pursuing low carbon and renewable energy programmes [21]. The UAE is aiming for nearly 20% of low-carbon electricity production from nuclear power plants and renewable energy by 2020.

Approximately 98% of the power generated in the UAE is currently from natural gas fired power plants [43]. Combined Cycle Gas Turbine (CCGT) technology is the most widely utilised and these plants traditionally operate continuously and at maximum efficiency to supply the base electricity demand [42]. They therefore tend to have poor operational flexibility. If the UAE national energy policy continues as planned to 2030, renewable energy projects will account for more than 6.5 GW of the power generation mix and will be predominantly derived from solar power with photovoltaic (PV) cells considered to be the highest potential technol-

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ogy [21]. Nuclear power shall compromise of 5.6 GW of generation capacity and clean coal shall compromise of 3.6 GW. These new low-carbon power penetrations will demand a greater flexibility within the existing robust and heavily inclined base load CCGT power system.

The existing CCGT power plants will be required to operate on a more flexible basis to account for load variations and two shift operations caused by the solar PV generation which is intermittent and totally absent at night [23]. Older and more inefficient CCGT plants, originally designed with base load dispatch characteristics, will become forced out of the market place by the new more efficient and lower cost merit plants. This will have a detrimental effect on the economic viability of older generators and in order to survive in the new marketplace, it is necessary that they adapt to more flexible operations [17].

Cyclic operation via daily start/stops, fast loading and part-load operation for a CCGT plant introduce new mechanisms of damage and increase deterioration on CCGT plant's components. This can reduce the reliability and lifetime of the plant and increases maintenance and repair costs [35]. Bullinger [10] shows that by introducing advanced CCGT technology or by facilitating existing CCGT units to operate more flexibly, either though enhanced design features and components or through open-cycle operations, the impacts of cyclic operation may be reduced. CCGT plants will therefore have the opportunity to continue generating power and revenue during times when they would otherwise be shut down.

The study undertakes a techno-economic analysis of the operational flexibility of advanced CCGT technology to meet the UAE's changing power generation profile. By defining the technical and economic impacts of the introduction of low carbon and renewable energy on the existing power grid, the objective of this study is to qualify the technical and economic opportunities and challenges of the UAE's energy transition. In particular, the Levelised Costs of Electricity (LCOE) for traditional and advanced CCGT were examined as they are a useful measure for quick cost comparison between different power generation technologies. This is especially true in the UAE electricity market where production and selling prices are regulated by the government. The LCOE model outputs summarise the overall financial competiveness of the different CCGT technologies for the UAE up to the year 2030. The study aims to conveniently facilitate future discussions on the opportunities and challenges of the UAE's energy transition for developers, electricity suppliers and national policy makers.

Methodology

The operational benefits of advanced flexible CCGT technology for the future UAE energy market was performed by analysing LCOE results. The LCOE facilitated the comparison of the cost of producing one kW h by different technologies. The output of the LCOE calculation was reviewed against the major market drivers for the UAE energy transition, namely; low investment costs, high thermal efficiencies which reduce fuel costs and limit CO_2 emissions, high operational flexibility and high availability. The final output of the LCOE results in a specific cost that was calculated with a set of assumptions. Therefore a sensitivity analysis was conducted to provide a better understanding of the factors which may have a large impact on the LCOE calculation.

LCOE model

The LCOE of a given technology is the ratio of the total costs (including capital and operating costs), to the total amount of electricity assumed to be generated during plant lifetime. Both the total costs and the amount of electricity are quantified in Net Present Value (NPV) terms. This means that the future costs and generation are discounted when compared to today's values. LCOE can be considered as the price at which the electricity must be sold at to break even over the lifetime of the asset. It is an essential economic concept that any power generation plant costs should be recovered by the useful energy it produces over its lifetime [34]. The advantages of using a LCOE calculation is that standardises the units of measuring the lifecycle costs of producing electricity thereby easily facilitating comparisons of the competiveness between power generation technologies with different operating characteristics [44]. Given the structure of the electricity market in UAE where production and selling prices are regulated by the government, the LCOE is an excellent measure for cost comparison between different power generation technologies.

For this study an excel spreadsheet model was developed to calculate and compare the LCOE for different CCGT technologies. A key feature of the model is that it is flexible to allow the introduction of different scenarios and inputs upon which the impact in variation can be examined. Key inputs to calculating LCOE included capital costs, fuel costs, discount rate, fixed and variable Operation and Maintenance (O&M) costs, power output, plant efficiency, degradation rate and an utilisation rate for each technology. Fig. 1 depicts how the LCOE was calculated in a flow chart format.

The LCOE was calculated using the formula described in Eq. (1) and is denoted in US cents/kW h.

$$LCOE = \frac{CC \times PC + \sum \left[\frac{FC\times(1+FE)+FO\,\&\,M\times PC+VO\,\&\,M\times MW\ h\times(1-DF)^n}{(1+DR)^n}\right]}{\sum \frac{[MW\ h\times(1-DF)]^n}{(1+DR)^n}}. \quad (1)$$

where,

CC: Capital Costs; PC: Plant Capacity; FC: Fuel Costs; FE: Fuel Escalation; FO&M: Fixed O&M Costs; VO&M: Variable O&M Costs; DF: Degradation Factor; DR: Discount Rate.

The LCOE model output represents a minimum breakeven tariff in US cents/kW h for each CCGT technology. All costs presented in this paper are based on 2015 $. The exchange rate considered in the LCOE model is 1 UAE Dirham (AED) = 0.27220 US Dollar ($). It is important to note that the AED is pegged to the $ so the currency exchange rate is fixed [26].

Factors that influence the LCOE

Fossil fuel technologies such as CCGTs which have significant fuel costs over the plant lifetime are significantly affected by both the fuel costs and capital costs in the LCOE calculations. The use of fuel subsidies that lower the fuel price and any other incentives or taxes, such as tax credits or emissions taxes, can also impact the LCOE calculation. As with any assumption, there is an element of uncertainty and the actual values will change across different regions and also with time as technologies advance and fuel prices change [31].

The capacity factor is also influential and it depends on the power generation mix and the load characteristics of the locality. Since power generation output is a core piece of a LCOE calculation and is inversely proportional to the total costs, the higher the capacity factor the lower the generation cost. It is also noted by the EIA [16] that since load must be continuously balanced; flexible units whose output can be varied to follow demand typically are more valuable than less flexible units such as base-load thermal plants or intermittent renewable energy sources.

Sensitivities

LCOE calculations are highly sensitive to the underlying data and assumptions used including those on capital costs, fuel prices,