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The feasibility of the introduction of natural gas into the electricity production system in the island of Crete (Greece)

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ABSTRACT

This article examines the technical and economic feasibility for the introduction of natural gas for electricity generation in non-interconnected insular systems. In such systems, the introduction of natural gas constitutes a fundamental perspective towards the substitution of oil or coal, commonly used for electricity production. On the contrary, the expensive transportation of natural gas for long overseas distances, the required technical infrastructures and the expected limited consumption of natural gas in islands with low populations, constitute issues that can negatively affect the feasibility of the project.

The aforementioned tasks are examined in the present article for the island of Crete (Greece) chosen as a case study. The size of the island and its consequent electricity consumption create the fundamental prerequisites for the introduction of natural gas. The annual operation of the existing system and the new one, as it would be modified after the natural gas introduction, is simulated using all the required parameters and data as provided by the utility company. The annual production specific cost is calculated for both systems and the economic benefit from the substitution of oil with natural gas is evaluated. The CO_2 annual emissions are also calculated for both systems.

The annual electricity production cost in Crete with the introduction of natural gas is reduced 38%, while the CO_2 annual emissions are reduced 54%, compared to existing levels in 2013. The required investments exhibit a payback period above 3.5 years. On the other hand, the energy dependence of the island on imported energy sources remains.

Introduction

The existing situation in the electricity production sector in Crete

The electricity production in Crete is based on three thermal power plants and on a dispersed network of wind parks and photovoltaic stations (PV). The system is not interconnected.

The electricity generation system in Crete is characterised by several technical and economic inadequacies that can be summarized as follows (see also The existing electricity system in Crete and Results sections):

- the high installed power capacity of gas turbines compared to the installed power of the base thermal generators;
- the high annual consumption of expensive diesel oil by combined-cycle power plants and gas turbines;
- the frequent power interruptions during summer peak periods, whenever the power demand exceeds installed thermal generation capacity;
- the necessity to maintain thermal spinning reserve to improve the system's dynamic security, a procedure that implies the operation of the thermal generators close to their technical minima, with low efficiency;
- the dependence of electricity generation on imported fossil fuels with all the well known negative consequences (low energy security, increase of fuel prices);

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- the final electricity production cost higher than 20€/MWh, including all the involved components (fuel consumption, equipment maintenance, salaries, etc.);
- the emission of more than 1.5 million tonnes of CO_2 annually due to the consumption of heavy fuel oil and diesel oil.

It is obvious that the above features imply an operation of the electricity system in Crete far from the optimum one, which is determined by the secure and uninterrupted electricity production with a considerably reduced electricity production cost.

The rationalism of the electricity production system in Crete should aim at the following objectives:

1. The elimination of the dependence of the electricity supply on imported fossil fuels, which will strengthen the energy security of the island and enable the independence of the electricity production cost from the international variation (usually increase) of the fossil fuel prices.
2. The improvement of the system's dynamic security and competence, which will contribute towards the elimination of the occurred electrical contingencies and the improvement of the provided power quality.
3. The minimisation of the environmental effects of electricity generation.
4. The reduction of electricity production cost.

A considerable number of relevant studies (Mourelatos et al., 1998; Tsioliaridou et al., 2006; Tsoutsos et al., 2009; Giatrakos et al., 2009; Kaldellis et al., 2013) have been presented so far, examining different schemes for the secure and cost-effective electricity production in Crete. The proposed solutions can be summarized as follows:

1. Introduction of natural gas, a cheaper and environmentally friendlier fuel, as the main fuel in the thermal power plants, substituting the currently consumed heavy fuel oil and diesel.
2. The interconnection of the Cretan electricity system with the Greek mainland, which will enable the elimination of the expensive diesel oil consumption. The electricity generation cost will approach that of the mainland system and the greenhouse gas emissions in Crete will be reduced. Finally, the energy security of the power system will be considerably improved.
3. The maximization of Renewable Energy Sources (R.E.S.) penetration for electricity generation, combined with storage technologies, which will contribute to the reduction of the:
   a. dependence of the autonomous system on imported energy sources;
   b. greenhouse gas emissions;
   c. high electricity production cost, usually met in autonomous insular systems.

The present article examines the feasibility of the introduction of the natural gas in the electricity system in Crete, completely substituting liquid fuels that currently constitute the main energy sources for the electricity production. A design towards this target has been developed by the Power Production Corporation (P.P.C.), the national utility company in Greece. This design is adopted in this paper.

Natural gas — attributes and existing technologies

Natural Gas (NG) comprises one of the fundamental fossil fuels, exhibiting a 2.5% annual consumption global increase during the last decade. The annual NG production ($3.4 \cdot 10^9 Nm^3$) covered 23.9% of the global energy demand in 2012 (BP Statistical Review of World Energy, 2013). This percentage is expected to reach 50% until 2020 (Economides et al., 2000).

Compared to the liquid fossil fuels, NG exhibits the following advantages:

- the lower gaseous emissions from NG consumption in internal combustion engines (Papakonstantinou, 2008);
- the lower NG price;
- the NG reserves' longer life period.

On the other hand, the considerable CH_4 leakage throughout the NG production, transportation and consumption should be mentioned. This leakage may exceed 2% of the total NG annual production. The global warming potential (100 year time horizon) of methane is 28, according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014).

Due to the geographic concentration of NG in specific areas on earth, the NG consumption requires a wide transportation network. The NG is transported either through pipelines (70%) or as Liquefied Natural Gas (LNG) with ships (30%). Recently, Compressed Natural Gas (CNG) has also been proposed for overseas transportation. It is less expensive to transport natural gas in a pipeline for larger demand volumes and shorter distances, while LNG is preferred for smaller demand and larger distances (Schwimmbeck, 2008).

LNG transportation requires the installation of large and expensive cooling, storing and regasification infrastructure (Marks' Standard Handbook for Mechanical Engineers, 2007). CNG shows lower production and storage cost compared to LNG as it does not require an expensive cooling process and cryogenic tanks (Dunlop and White, 2003). CNG requires a much larger volume to store gas equivalent compared to the respective gasoline or diesel.

Aim of the article

This article investigates the techno-economic feasibility for the introduction of NG for electricity generation in Crete, in favour of the P.P.C. The potential benefits for local communities are also examined. The feasibility of NG introduction in Crete is investigated under the following parameters:

- possible reduction of the annual electricity production cost;
- possible environmental benefits;
- energy supply security;
- other potential benefits for the local communities in Crete.

The existing electricity system in Crete

In the following subsections we present the power demand in Crete (Power demand section) and how this demand is met by thermal power plants (The existing thermal power plants, The dispatch order of thermal generators, and The thermal generators spinning reserve sections) and renewable power plants (Renewable energy power plants in Crete section).

Power demand

The P.P.C. provided the necessary data concerning the operation of the existing electricity system in Crete. The 2013 annual power demand time-series of mean hourly values is presented in Fig. 1. Characteristic features concerning the annual electricity consumption and power demand in Crete in 2013 are provided in Table 1.

Fig. 1 shows the seasonal variation in power demand, caused mainly by the increased tourism activities in summer. Table 1 shows that there was a considerable difference of more than 400 MW between the maximum and the minimum power demand in 2013. This power demand fluctuations lead the system to operate under significantly different conditions and renders the uninterrupted and secure power production a difficult task.