Planning of a Quadgeneration power plant for Jammerbugt energy system

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Abstract

Quadgeneration is the simultaneous production of power, heat and cooling and different fuels from flexible feedstocks such as biomass, waste, refinery residue etc. In order to accommodate more renewable energy into the energy system, it is extremely necessary to develop new flexible power plants that can quickly increase or decrease the production of electricity. Such plants should be ultra flexible in terms of production and able to run on many different types of fuels, with one of its major outputs being liquid fuels for the transport sector. The aim of this paper is to integrate district heating energy technology into a Quadgeneration energy system at Jammerbugt municipality in the north of Denmark in a creative and innovative manner that can reduce CO_2 emission and fuel limitations, whilst not compromising security of delivering heat and power to the local resident. So, it is essential to think about the design and co-optimization of energy system in this area. ASPEN Plus is used for process integration, where energyPRO is suitable for the investment planning and economic analysis. And also some CFD (Computational fluid dynamics) simulations shall have done for correct measurement of some equipments in the Quadgeneration power plant. This paper presents two models for the investment planning of a Quadgeneration energy system in Jammerbugt municipality, and uses these models for different case studies addressing the system for production of heat, cooling, liquid fuels and electricity.

Keywords

Quadgeneration, Planning, Jammerbugt, Energy system.

Introduction

The Danish Government's policy is that Denmark must be a green sustainable society. The stabilization of the Danish primary energy supply over more than three decades shows that the ability to act as a society has been possible despite conflicts with representatives of the old technologies. In Denmark, the description of concrete technological alternatives and alternative energy plans has played an important role. Denmark should also be among those three countries in the world which increase their share of renewable energy the most up to 2020 [1]. At present the share of renewable energy is coming close to 20 per cent. From such point of

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departure, a scenario framework has been established in which the Danish system is converted to 100 percent Renewable Energy Sources (RES) in the year 2060 including reductions in space heating demands by 75 percent [2]. A technical report has published which identify the role of polygeneration on a European level and document the activities taking place in Europe [3]. Energinet.dk, the owner of the overall energy infrastructure in Denmark, has allocated almost DKK 29 million for a consortium that develops the ultra-flexible power plant of the future [4]. Energy is an essential factor required for the development of societies and countries, but at the same time it represents a problem for an appropriate sustainable development. Energy is required for developing whatever activity in whatever field (education, health, agriculture, food production, water supply, industry and so on) but its present utilization represents one of the most important sources of environmental pollution and greenhouse gas emissions. In 2004 the total primary energy supply of the world was 11059 Mtoe (Million Tons of Oil Equivalent), and 80.3% of this energy supply came from fossil fuels [5].

Innovation in power generation technologies for higher efficiency and lower emissions has never ceased over the decades: the Integrated Gasification Fuel cell (IGFC) power plant combines a gasifier, a fuel cell and a steam turbine cycle for power generation, not only delivering reliable performance but also increased efficiency [6]. Statistics show that industry, transport and residential sector are the main energy consumers. In this respect, polygeneration technologies, more developed in chemical [7] and energy processes [8] but clearly unexploited yet provide: Maximum energy usage as a consequence of increasing energy efficiency, reduction of unit cost of final products, reduction of environmental burden.

A number of scientific publications address the mathematical modelling and simulation of polygeneration energy systems. However, they either focus on the evaluation of new plants and technologies [9] on the configuration design of processes [10]. Research in large-scale investment planning with the existing plant for polygeneration energy systems has been limited, albeit clearly crucial for strategic policy-making in regions and countries. The concepts of polygeneration and energy integration have been described with various examples of systems [11].

This study is carried out to select the best plan among many possible alternatives, according to explicit economic objectives, and subject to quantified technical and environmental constraints that vary by region. It is also describing the future technological involvement of the future Quadgeneration energy system in Jammerbugt region.

Present heating system

Jammerbugt is one of the eleven municipalities in the North Jutland region (Figure 1). It has twelve district heating plants. Figure 2 shows the thermal basis for the 12 district heating plants in this municipality and the primary fuels that have been used for these plants. The total heating base is 252,200 MWh/year, of which four major works (Fjerritslev Aabybro, Jetsmark and Brovst) account for 78% combined. Seven of the plants have natural gas as primary fuel, four of them have woodchips and a single (Vr. Hjermitslev) has biogas. The purpose of this paper is to incorporate a Quadgeneration power plant with the existing district heating power plant in the Jammerbugt municipality.

Figure 1: Denmark with Jammerbugt located in the North.

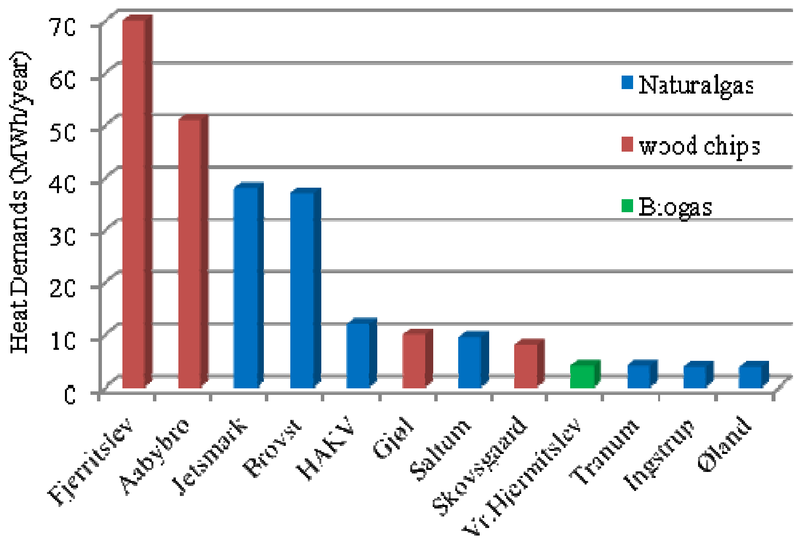

Figure 1: Heat demand and primary fuels for the 12 district heating plants in Jammerbugt municipality.

Scope of this Work

Jammerbugt municipality has a plan to combine all the decentralized heating plants to a district heating network. A plan for this region is to integrate all electricity, heating, cooling and transportation demands. Based on that scenario, it will be analysed to convert the possible district heating plant to Quadgeneration plant which may helps to be 100 % renewable on the total energy system.

And also the use of fossil fuels is associated with a lot of concerns; among these the security of supply and air pollution associated with the combustion of fossil fuels – both local pollutants such as NO_x, SO_x and also CO_x. One of the ways of reducing the transportation sectors dependency on fossil fuels is by using biofuels from the Quadgeneration plant. In this region, a large amount of electricity is being produced by wind frams but the output is always fluctuated according to the availability of wind. So this Quadgeneration power plant can make room for those wind energy as it's possible to produce flexible output.

Modeling and simulation of Quadgeneration system

A model of process simulation, CFD simulation and economic analysis will have been done towards design, investment planning and optimization of this Quadgeneration system. Here an introduction for different softwares which we will use for our case evaluation has discussed.

ASPEN Plus:

The proposed Quadgeneration process will be simulated using ASPEN Plus [12]. The ASPEN model of the Quadgeneration plant consists of some individual sections: (1) CHP (combine heat and power) or gasification process, (2) Heat pump process, (3) Refinery synthesis process, and (4) the whole Quadgeneration the power plant. All models of each part are built in the mechanism model. Based on the literature [6,13] and the data given by the different local district heating companies, a series of specified parameters for the process will be selected, while the thermodynamic properties (such as RK-SOVE, ELECNRTL, PR-BM) will be selected specifically for each process.

energyPRO :

energyPRO [14] is an input/output software tool which is used for modeling energy systems including polygeneration plant. Carrying out feasibility studies for Quadgeneration plant is one of the most important steps in the decision-making process. energyPRO allows the user to carry out a comprehensive, integrated and detailed technical and financial analysis. A recent comparison [15] of the features of different software packages available in the market (for instance AEOLIUS, COMPOSE, EnergyPLAN, HOMER, INFORSE, TRNSYS16 and some custom build models) concludes that energyPRO is a powerful and flexible application. The main features and evaluation mechanisms of energyPRO are described briefly here.

energyPRO has three different modules: design, finance and accounts. The design module includes the design and optimization of a specific operation year. The finance module will allow the project to be evaluated over a number of years, and detailed cash flows can be obtained. The accounts module allows a deeper level of financial analysis (it includes taxes, depreciation and others).

energyPRO model calculates annual productions in steps of, typically, 1 h. The inputs are capacities, efficiencies and hour-by hour distributions of heat demand and electricity sales prices. The period of optimization is divided into calculation periods, where everything is constant, for example temperature, solar radiation, priorities, heat demand, electricity demand, cooling demand, production capacities and fuel deliveries.

ANSYS CFD:

Computational fluid dynamic (CFD) analysis [16] provides crucial insight of the different individual parts of power plant. It also presents the advanced geometry acquisition, mesh generation mesh optimization and post processing tools to meet the requirements for integrated mesh generation and post processing tools for today's sophisticated analysis.

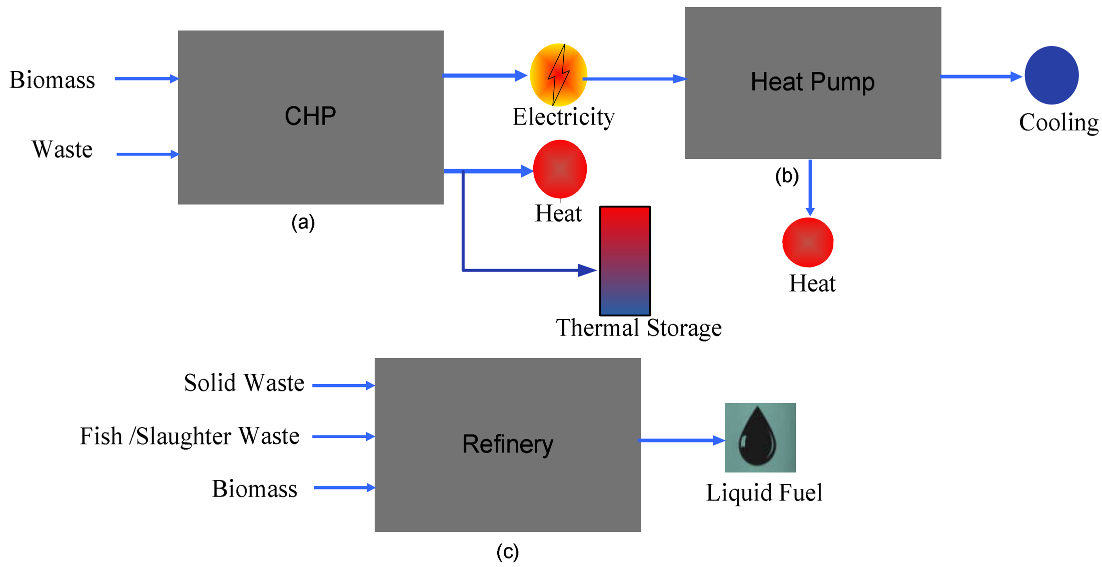

Figure 3: Quadgeneration energy system with existing district heating plant.

Case studies and Results Discussion

Case 1: The case study using the model focuses on investment planning of Quadgeneration energy systems with different productions (heat, cool, electricity and liquid fuels) at Jammerbugt in near future. Figure 3 illustrates the model for this case. The feedstocks which are available locally will be used in this power plant. For this case only heat pump and refinery equipments will attached in the existing district heating plant. Electricity produced from CHP (combine heat and power) plant will be utilized for the heat pump which will produce cooling for the end users. One additional part of refinery system will introduce here for the liquid fuel production (Figure 3). All the individual system will have stimulated by ASPEN Plus software. Besides the thermodynamic analysis, a techno-economic analysis of this system will also be done with energyPRO software which will help to establish this model in the economical point of view. And then system analyses will be verified by system simulations through economical point of views. This makes a highly flexible power plant that can run on a number of different fuels and produce electricity, heat, gas, or liquid fuels depending on what is required.

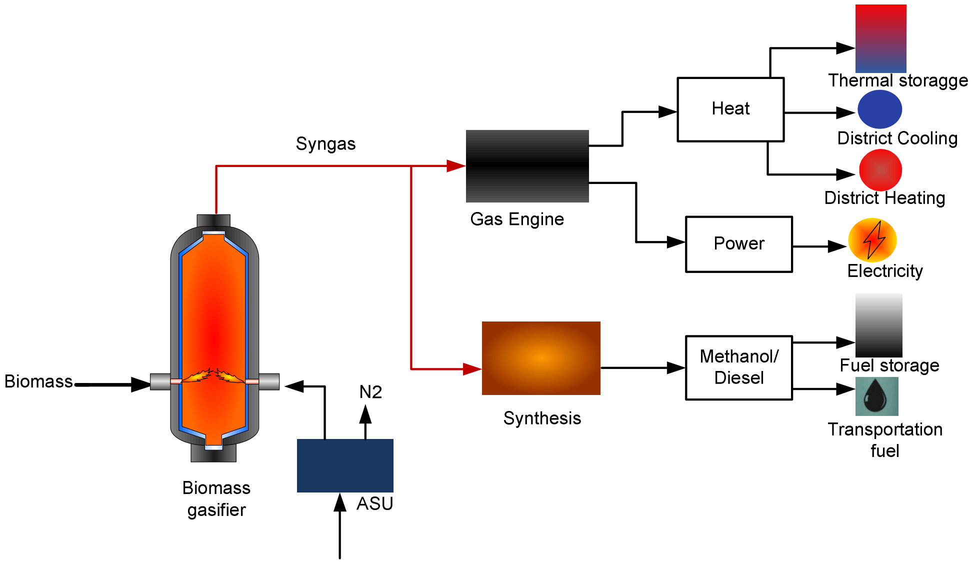

Figure 4: Quadgeneration energy system with gasification unit.

Case 2: In this case, the Quadgeneration plant consists of a gasification unit, where the primary fuels are converted to gas at high temperature by adding oxygen from air. The syngas consisting of CO and H_2 is then used for both the gas engine and synthesis unit which will convert the gas to methanol/DME under high pressure and after this, a distillation step separates the produced products. The gas engine will produce both heat and power which are used to the end users (Figure 4). It is also possible to introduce a heat pump which will use the power output from the gas engine and produce both district heating and cooling. This heat output can be utilized for district heating, district cooling and also for the storage purpose. The simulation for this model is also following the same procedure like case 1.

We will select some boundary conditions for the both cases of the Quadgeneration system, and then simulate the different cases with the process simulator ASPEN Plus, CFD and energyPRO. The ASPEN Plus result sheet will be utilized for the CFD simulation for plant components. The spot market data which will be used for the energyPRO simulation will take from the Energinet.dk and also via Nord Pool's webpage. Mass flow and energy flow rates of each process which we will be obtained from the simulation results, will help to find out the way to improve the efficiency of the plant. For the environmental analysis energyPRO will measure how much of CO_2, SO_2 and NO_2 will emitted from the plant and its cost according to energy input of the system.

Superstructure based modelling strategy, along with ASPEN plus, energyPRO and CFD are efficient and effective in solving energy systems engineering problems, especially at decision making and planning stage. Based on this, multi-objective optimization and optimization under uncertainty produces further in-depth analyses and allows a decision maker to make the final decision from many aspects of view.

Conclusion

A Quadgeneration energy system can improve profit margins and market penetration, decrease capital investment, reduce environmental emissions and increase feedstock flexibility crucially. Applications of this methodology to Quadgeneration energy systems infrastructure planning problems will prove its superior ability to solve large-scale real industrial cases and its great potential to be more widely applied in energy systems engineering fields. According to the opinions of different plant owners, they are mostly interested into the Quadgeneration system since it is possible to add some additional parts to their existing plant equipments. For this reason, case 1 having conventional combustion system might be preferable for this region instead of building new technology.

This study will find a way of planning to incorporate district heating energy technology into a Quad-generation energy system which can provide flexible outputs according to their needs that can reduce environmental emissions and fuel limitation.

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