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Comparison of linear, mixed integer and non-linear programming methods in energy system dispatch modelling

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ABSTRACT

In the paper, three frequently used operation optimisation methods are examined with respect to their impact on operation management of the combined utility technologies for electric power and DH (district heating) of eastern Denmark. The investigation focusses on individual plant operation differences and differences between the solution found by each optimisation method. One of the investigated approaches utilises LP (linear programming) for optimisation, one uses LP with binary operation constraints, while the third approach uses NLP (non-linear programming). The LP model is used as a benchmark, as this type is frequently used, and has the lowest amount of constraints of the three. A comparison of the optimised operation of a number of units shows significant differences between the three methods. Compared to the reference, the use of binary integer variables, increases operation of selected units by 23%, while for a non-linear approach the increase can be higher than 39%. The results indicate a higher coherence between the two latter approaches, and that the MLP (mixed integer programming) optimisation is most appropriate from a viewpoint of accuracy and runtime.

1. Introduction

Increasing use of intermittent sources for power production may imply several severe effects in stability, economy and maintenance of central electricity production [1,2]. In areas with large shares of CHP (Combined Heat and Power) production, introduction of intermittent power production may further influence the operation management, as an increasing amount of operational constraints is included in the optimisation. Operation of some CHP-units may be required in order to satisfy heat demand, in time periods where utility production is not economically desirable for the plant operator. Methods to decouple the production constraints of the coproduced products, while maintaining the high energy efficiency, are investigated as they may prove highly valuable. DH (District heating) network heat pumps may pose this ability [3–7].

In a liberalised energy system the operation pattern of each plant is determined by optimisation of economics, such that the consumer prices are minimised in each time period. In the present work, different approaches to optimisation of operation are investigated and compared, in order to determine whether the choice of optimisation algorithm affects the results. The investigated energy system consists mainly of CHP-plants, boilers and heat pumps, constrained by high amounts of intermittent electricity production from wind turbines. In the strictly linear models, the outlines of thermal units such as CHP-plants appear to be simplified to an extent where the representation of the plant does not characterise the physical unit satisfactorily. Two alternative methods provide the possibility to increase the detail of the constraints.

When using a modelling approach to evaluate the interaction of several multi product technologies, early choices such as the applied modelling scheme may influence the final results significantly. In the case of heat pumps in a DH-network, the economic feasibility of the individual energy technologies will depend on several factors, e.g. the amount of annual operation hours, the average load, or an economic incentive in operation of the combined system. If the used modelling approach has significant influence on operation results, the economically optimal investment may not be derived, which will influence the cost of utility for society and the revenue for the investor.

A number of energy models has been developed during the last decade both with specific focus on the Danish system and for more general application [8–11]. Many of these models are continuously expanded and maintained. As noted by Connolly et al., many of the system models will require long training periods, depending on the level of complexity required. In the advanced models, the detail

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level of individual technologies is not easily changeable, as the optimisation approach is a basic property of the model. The majority of the models is using linear optimisation [8].

The focus of this paper is to investigate and evaluate the impact of the choice of optimisation algorithm in energy system dispatch models. This choice will influence details of the calculated operation and load characteristics of individual technologies. As the derived operation characteristics are used in economic evaluations, faulty or incorrect estimations may impact the applicability or feasibility of a technology in the derived energy system.

The evaluation is based on a comparison of three different optimisation methods for an energy system model. The detail of the linear dispatch models used in the investigation represents the detail level of the technologies and demand characteristics in many of the considered references.

In the paper we describe the different detail levels of a dispatch models which represents the dynamic operation of heat and electricity markets. The production units in the system are represented by performance characteristics that account for the system parameters, such as temperatures in the DH-network and heat consumer units.

1.1. Energy system layout

As a specific case, the utility system for electricity and heat production of eastern Denmark has been used. The examined energy system has been chosen, as this is identified as a system, where heat pumps may contribute significantly in balancing both electricity and heat production with their individual demands.

The current utility production in this area distinguishes the system from other European utility areas, as electricity is only produced by wind turbines and CHP-plants. According to the statistics for the combined Danish energy system [12] (including the area of western Denmark) more than 99.7% of the produced electricity in 2011 originates from these two utility technologies.

Historical data are available online for the Danish electricity production and consumption in each region and for different production technologies from the TSO (Transmission System Operator) [13]. Hourly values for wind production, local production (decentralised CHP-plants) and gross consumption are used. The used data from this source is from January 2011.

The thermal electricity production in eastern Denmark origins from both small decentralised and large centralised CHP-plants. Out of 14 central power plant units, 10 are steam turbine-based CHP-plants, where a high part of the electricity is produced with simultaneous production of heat. Additionally, in 2011 there were 4 central CHP waste incineration steam power units in the energy system layout. In terms of installed capacity for electricity production the incineration plants represent a small fraction.

Most of the required heat production is handled by the abovementioned units, although additional DH incineration boilers are in use. For the majority of the central CHP-units and incineration plants, the produced heat is transmitted to one large DH-network that covers Copenhagen and the surroundings.

Two independent DH-networks have been included in the optimisation. The larger one (in reality consisting of three interconnected DH-networks) covers the major part of Copenhagen and suburbs, while the second network supplies heat to Kalundborg, a town in the western part of Zealand. The hourly demand of the networks has been collected from one of the network operators [14] for the entire year 2011. The data received is subdivided into five areas, ranging from central Copenhagen to one of the low intensity suburbs, and is thus considered representative for all the areas in the study. The hourly demand of the different DH-networks has been scaled by their individual yearly consumption. The derived central electricity demand and the total heat demand in the four DH-networks for January 2011 are presented in Fig. 1.

A graphical representation of the included technologies is shown in Fig. 2. The DH areas 1–3 are connected, and the capacity of the connections is not considered. Each plant in the figure represents one or more individual units. Only the large wind farms are included in the figure, but the total wind power capacity is included in the calculations. Transmission lines for import and export are not used in the analysis for this paper. The operation can thus be characterised as island operation.

1.2. Optimisation of utilities

In a liberalised electricity market, the installed utility technologies are cooperating in the effort to match electricity production and demand. The optimisation of electricity cost is handled by a common Nordic and Baltic market operator, while grid stability is handled by the TSO of the considered area. The optimisation is performed on a daily basis. Prices are calculated based on supply, demand and transmission capacity for the combined area, and the individual transmission systems. By accepting hourly- or block-bids from the power plant operators, the system operator decides the optimal allocation of power production between the producers.

For each individual DH-network, a similar system optimisation yields the cost of heat and the allocation of production. This optimisation is based on another set of production bids and demand characteristics. The combination of the two individual optimisations determines the production outlines for the individual utility producer for a given hour. The producer finally determines how he wishes to fulfil the production responsibility at the available units.

The production bids are based on various factors such as fuel prices, efficiencies and other variable cost. The bids can include both linear and non-linear constraints. The effect of some selected non-linearities is considered in this paper.

With fixed production bids from the producers, the production price is given and the system operators can optimise the utility cost using simple optimisation methods.

For the comparison of optimisation approaches, the optimisations performed in this paper is only the variable cost related to the consumption of the fuel. There are several reasons:

- The capital costs of already installed power plants can be considered sunk costs in the evaluated system.

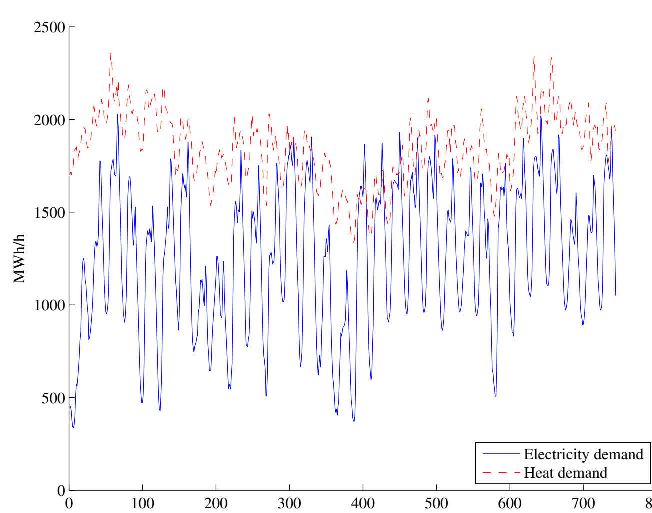

Fig. 1. Total electricity and heat demand for the considered units in January 2011.