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Practical and accurate measurement of cogenerated power

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Abstract

The performance of CHP activity is measured by the amount of cogenerated electricity (E_{CHP}) during a considered period. It is the proper yardstick because it combines attributes of quality (power-to-heat ratio **σ**) with those of quantity (recovered heat Q_{CHP}), given that $E_{CHP} = \boldsymbol{\sigma} \times Q_{CHP}$ is a commonly accepted identity. In practical applications of the formula, problems arise in finding the appropriate numerical values of power-to-heat ratios. The EU Commission, expert groups, and published literature expose circular logics, concealed by flawed approximations. The enigma is most relevant for extraction-condensing steam turbines, which mix cold condensing with one or more cogeneration activities, making the power flow E_{CHP} not directly observable. This paper presents a generic and neat solution to the E_{CHP} measurement problem. It starts with a clear problem statement. Then, the components of the solution are exposed. First, in a Mollier diagram the unit mass flow expansion path of a Rankine steam cycle with backpressure heat extraction(s) ahead of the cold condenser is noted. Second, the characteristic points on the expansion path provide the contours of the (Electricity E – Heat Q) production possibility set of the steam power plant. Third, the real capacities of the steam flows of the power plant are mapped on the possibility set expressed in electricity and heat capacity (Watt). It shows how limits on extracted steam flows truncate a significant part of the theoretical possibility set in an extraction-condensing turbine. By merging the extraction capacities with design characteristics of a plant, the accurate measurement of cogenerated power becomes self-evident. The method is documented with numerical cases. Applying the presented, transparent and accurate, method is prerequisite for regulations being effective in promoting optimal CHP plant investments and operations. Promotional support may imply subsidies for energy efficiency, priority ranking of cogenerated power in merit orderings of integrated power systems, among others.

Keywords: Extraction-condensing steam turbine; quantify cogenerated power; power-to-heat ratio; production possibility set; incentive regulation

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1. Introduction

Combined Heat & Power (CHP) plants are one of the major heat sources in District Heating (DH) systems. In 2014, 61.1% of Danish thermal electricity production was produced simultaneously with heating, and 68.9% of district heating was produced with electricity [1]. Large-scale DH networks often source the major share of the distributed heat from large steam power plants, designed as extraction-condensing Rankine cycles. This type of plants likely delivers the major part of globally cogenerated electricity. The word 'likely' in the preceding sentence is necessary because there is no agreement about a standard method for measuring the quantity of cogenerated electricity in plants where cogeneration and condensing activities occur simultaneously. At the plant's alternator but one current is sent out and metered by the plant operator. The metered quantity is the sum of two electricity flow components: cogenerated plus condensing power. Splitting the metered flow requires a computational method. The purpose of this paper is to illustrate a generic, proper and accurate splitting method [2]. The method is rooted in basic engineering thermodynamics [3], and the description is documented with a numerical example to emphasize the accuracy and the practicality of the approach.

In common language we speak about CHP plants when they deliver power and heat for end-uses. However, it is more accurate to specify that CHP is an activity occurring in a thermal power generation plant [4]. The activity may be added on (with no power output loss) or embedded in (with some loss of power output) the thermal power generation process. The plant may be equipped with one, or with more than one, opportunity to perform CHP activity. The CHP activities recover all or part of the point-source heat exhausts of the thermal conversion process. In this way, CHP also mitigates local thermal pollution, in addition to improving the overall efficiency in converting primary energy. Such advantages are the basis for public authorities eventually supporting CHP. Support systems function best when they apply effective and fair regulations, providing incentives to CHP actors to optimize performance and results [5-6].

The novelty of this paper is the combination of straightforward technical know-how (thermodynamic cycles) with concepts of economic analysis (production possibility sets), to develop a generic and accurate method solving the long-standing issue of splitting electricity flows metered in CHP plants. The method is applicable for all cogeneration technologies, and is fully transparent and manageable by regulators. It dissolves the present confusion forthcoming from differing practices adopted in various regions. For example, the European Union has formulated an approach in a Directive of 2004 [7], reconfirmed in 2012 [8].

Nomenclature

CHP	Combined Heat & Power
E_{CHP}	Cogenerated electricity
Q_{CHP}	Recovered heat
β	Power loss factor (heat for power substitution rate)
σ	Power-to-heat ratio

2. Background

The central indicator of performance of a CHP activity is the amount of cogenerated electricity (E_{CHP}) during a considered period. The amount of cogenerated electricity is linked to the amount of recovered heat (Q_{CHP}) from the thermal conversion process, by the equation $E_{CHP} = \sigma \times Q_{CHP}$, where σ is called the "power-to-heat ratio". Because Q_{CHP} is readily measured, for obtaining E_{CHP}, the crucial unknown is σ, representing also the quality of the particular CHP activity recovering the measured Q_{CHP}.