Energy 59 (2013) 642–651

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Calculation of the power loss coefficient of steam turbine as a part of the cogeneration plant

Dragan Urošević [a], Dušan Gvozdenac [b,*], Vojin Grković [b]

[a] Victoria Group, Hajduk Veljkova 11, 21000 Novi Sad, Serbia
[b] University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia

A R T I C L E I N F O

Article history:
Received 11 March 2013
Received in revised form
31 May 2013
Accepted 2 July 2013
Available online 3 August 2013

Keywords:
Power loss coefficient calculation
Cogeneration
EU Directives on cogeneration

A B S T R A C T

A cogeneration plant operates under very variable conditions within a reporting period (usually one year) and this frustrates the achievement of the high standards stipulated by the EU Directive from 2004. Taking into consideration these difficulties, one needs to start with the decomposition of the cogeneration plant in order to determine a virtual part of the plant that can meet the requirements of the Directive on the basis of conducted measurements and calculations. In this way, the plant can be partially qualified as eligible for economic and financial benefits.

The focus of this paper is an analysis of the power loss coefficient of steam turbines for the generation of useful heat energy and electricity simultaneously. This applies to all cogeneration plants comprising extraction-condensing steam turbines and combined cycles (gas turbine and steam turbine) when heat is extracted prior to the bottoming cycle. The proposed procedure for calculation of power loss coefficient is easily applicable in industrial practice. The viability of the proposed method is demonstrated in the case of calculations for a 10 MW_e (combined cycle gas turbine) plant.

1. Introduction

A practical need to define CHP (combined heat and power) and non-CHP processes has occurred as a consequence of implementing regulations based on which it is possible to obtain rights to certain economic and financial benefits. When it comes to the EU, this area is well defined in the Directive [1], as well as in other documents that are created later. In countries outside the EU, there are similar regulations with the main aim to promote cogeneration and control implementation of adopted energy policy.

The basic directive relating to cogeneration (EU Directive, 2004) [1] is aimed at promoting cogeneration. The legal basis for this directive is the Treaty Establishing the European Community [2] and many other subsequent documents. In 1997, the European Commission started work on regulations to promote cogeneration [3]. Even then, it was obvious that a political decision was needed in order to increase the efficiency of energy transformations by introducing cogeneration technologies and to make a start on readying the economic system for the implementation of the schedules set up for energy development in general.

At the end of 2000, the European Commission adopted a green paper: A European Strategy for Sustainable, Competitive and Secure Energy [4]. This is a key document expressing the political will to set out on the road of increased energy efficiency and the use of renewable energy sources. In this document, cogeneration is addressed as an important factor in increasing energy efficiency. It also considers the geopolitical, economic and environmental aspects affecting the strategy's success.

The enactment of similar binding political documents has led to the launch of numerous regulations, directives, decisions and recommendations governing specific fields [5–7]. A great many important documents related to cogeneration, energy efficiency, renewable energy sources etc. date back to the period before 2000, but it is fair to say that the Green Paper brings them together in a unique way.

The Directive [1] attempts to precisely define and distinguish the cogeneration process from actual complex energy systems. This should provide a clear basis for regulatory actions and the preparation of those mechanisms which will promote cogeneration and enable the construction of new plants. National energy policies primarily define the capacities of such plants and the timeframe for their construction. These objectives have determined the type and contents of national incentive mechanisms. Directives and accompanying procedures, which are subsequently enacted, directly affect the energy policy's implementation.

* Corresponding author. Tel.: +381 63 209 651; fax: + 381 21 6350 775.
E-mail address: gvozden@uns.ac.rs (D. Gvozdenac).

0360-5442/$ – see front matter
http://dx.doi.org/10.1016/j.energy.2013.07.010

A detailed list of European regulations regarding cogeneration and the analysis of problems caused by the use of these regulations is given in Ref. [8].

In practice, the degree of conformity of the plant's operations with applicable legislation is determined on the basis of certain energy indicators related to a concrete plant. Necessary energy indicators are determined on the basis of measurements. These are usually standard measurements necessary for running the plant. Insufficiently precise measurements and calculations in concrete industrial plants provide energy indicators which are not sufficiently reliable. It seems that there is still room for improvements regarding calculation procedures in order to provide reliable energy indicators for the verification of only cogeneration processes in complex energy plants.

Generally speaking, it can be said that all large cogeneration plants have been designed to primarily produce electricity [9]. The reason is that they can find a reliable market much more easily for this than for heat energy. However, guarantees need to be provided that electricity is being produced in the cogeneration process and that this process meets the previously prescribed efficiency conditions. This is necessary in order to receive economic and financial benefits and to comply with certain requirements regarding efficiency and primary energy savings. This has turned out to be a very difficult technical problem requiring precise measurements and the monitoring of the operations of the cogeneration plant.

Verbrunnen [10,11] provides critical analyses and indicates deficiencies in the 2004 Directive, clearly advocating the need for more complex CHP measurements. A complete procedure has been presented by Frangopoulos [12]. The paper also provides specific initiatives for the revision of procedures, both proposed and used. Medina-Flores and Picón-Núñez [13] analyze the thermodynamic model in order to reconcile the design of cogeneration systems using steam turbines and their thermal integration into background processes. The proposed analysis is comprehensive but not easily adaptable to practical industrial conditions for the assessment of cogeneration plant efficiency.

Complex cogeneration plants consist of various combinations of cogeneration and non-cogeneration technologies. There is no simple procedure to separate all non-cogeneration useful heat generation from the overall cogeneration plant. For each scheme, energy balance modeling has to be applied so that the amount of cogenerated and non-cogenerated useful heat can be calculated.

The papers [14–22] are dealing with different cogeneration schemes. The efficiency of the plant or some of its parts has always been in the center of the analysis with an aim to make comparisons with some other possible solutions or to determine the effects of some changes in the operation regime.

Directives and accompanying procedures for the verification of operations of cogeneration plants should be developed in two directions. Firstly, it is necessary to reconsider reference values which should be adjusted in such a way to fully support the energy policy in the field of cogeneration. Secondly, practical calculation procedures should be developed so that they are relied onto existing standard measurements in industrial plants to the maximum extent.

This paper deals with the problem of the practical evaluation of complex cogeneration plants that involve steam extraction-condensing turbines. Special consideration is given to the determination of the power loss coefficient, as this influences the efficiency of the cogeneration plant and is not adequately treated in the efficiency calculation procedure (CEN/CENELEC) [23]. Generally speaking, procedures proposed in Ref. [23] are very detailed and probably the best available for practical industrial application.

The consistent application of procedures from Ref. [23] and proposed calculation of power loss coefficient in this paper is demonstrated in the case of the 10 MW_e CCGT(combined cycle gas turbine) plant.

2. Cogeneration and non-cogeneration processes

Fig. 1 shows three processes which use the same quantity of fuel but involve different energy transformations. The first process on the left is the standard generation of heat energy found in boilers. In these plants, only useful heat energy is produced. On the right side, there is a depiction of electricity generation typical in standard thermal power plants. These plants use condensing steam turbines. The quantity of waste heat in these plants is much higher than in the process generating only heat energy. In the middle, there is a cogeneration-type process – the combined generation of heat and power. A CHP (combined heat and power) or cogeneration plant can sometimes, when necessary, also operate in a mode in which it generates only useful heat or only electricity. In case of CHP heat and power, the power process is somewhat lower than in case of non-CHP power. This is not the rule and depends on the plant itself. Fig. 1 should be observed as an illustration of possible processes of interest for this paper.

A combined heat and power plant can to a certain extent be designed to produce a variable proportion of useful heat to power. With such an option, the relationship between power loss and increased useful heat generation needs to be established. This is of particular importance when assessing the efficiency of the cogeneration plant or a part thereof in a complex energy facility which is to be regarded as cogenerating for the purpose of calculating possible economic and financial benefits. In such cases, it is necessary to decompose the cogeneration plant and separate the part which comprises cogeneration by definition. Only that part of the cogeneration plant complies with certain requirements prescribed by the regulator.

Cogeneration plants can be divided into those without power loss and those in which the occurrence of such loss is possible.

The ratio between the losses of power caused by ~~increased heat generation and~~the increase in useful heat generation, and vice versa, is called the *power loss coefficient (β)* and it is equal to [23]:

$$\beta = -\frac{\Delta e}{\Delta q} \geq 0 \qquad (1)$$

where:

$\Delta e = e_{\max} - e$ decrease in power due to heat generation in relation to the maximum possible in the analyzed plant at a given fuel capacity, [kW] (or [kWh] if energy is used),
$\Delta q = q_{\min} - q$ increase in useful heat ~~energy~~in relation to the minimum possible in the analyzed plant at a given fuel capacity, [kW] (or [kWh] if energy is used).

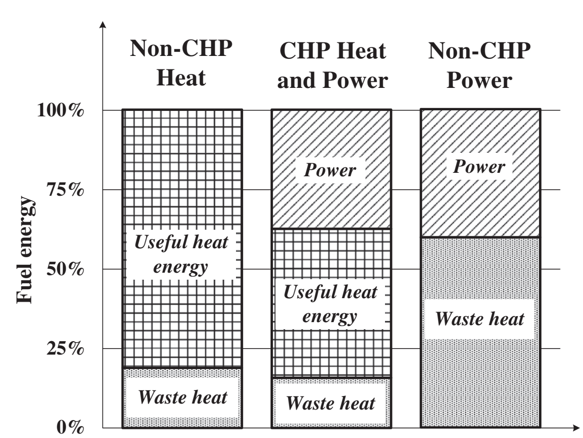

Fig. 1. Cogeneration and non-cogeneration processes.