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# Uncertainties in energy and exergy efficiency of a High Pressure Turbine in a thermal power plant

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ABSTRACT

In this study, uncertainties in isentropic and exergetic efficiency of a High Pressure Turbine (HPT) of large-scale lignite fired power plant have been analyzed for five different design power outputs (100, 85, 80, 60 and 40%) and by using one real data of the plant. Primarily, the differential method, which depends on the sensitivities of pressure and temperature, was used in carrying out this study. In addition, extreme case analysis was conducted in order to determine the boundaries of the uncertainties for the rare case occurrences. The range of uncertainties for isentropic and exergetic efficiency of a HPT were found to vary between 3.35%–2.62% and 2.55%–1.50% for a power output level of 144–360 MW, respectively. The differences in percentage between the possible maximum and minimum extreme values were calculated as 11.6% for isentropic efficiency and 6.6% for exergetic efficiency. It is concluded that the dependency of exergetic efficiency uncertainty is more sensitive to pressure whereas it is less sensitive to temperature variations.



## Introduction

The energy and exergy efficiency of each component of a power plant is a very important parameter. Moreover, equally necessary is the correctly determination of the uncertainties associated with sensitivity of the measuring devices. In practical applications this issue becomes quite critical, as during the process of device measuring data, the errors have a negative impact on the efficiency calculation. Therefore, the uncertainty analysis becomes as important factor.

In the literature, there are a large number of papers on the energy and exergy analysis of steam and gas turbines. Regulagadda et al. have analyzed relatively a small coal fired power plant with measured boiler and turbine losses characterized by deterministic values of efficiencies of the components [1]. Struchtrup and Rosen have studied how much work is lost in an irreversible turbine when discussed on the basis of isentropic and exergetic efficiency. They show that isentropic and exergetic efficiency of a turbine can sometimes differ significantly [2]. Zaleta-Aguilar et al. have focused on concept of exergoeconomic audits and evaluation of steam turbines. Their analysis allows evaluation of different malfunctions of the components of a turbine and the evaluation of the faults by means of exergoeconomics theory [3]. However, none of their results and conclusions refer any uncertainties in the resulting figure of the study. Bresolin et al. have discussed Fourier transform method for sensitivity analysis in coal fired

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**Nomenclature**

| | |
|---|---|
| $h$ | Enthalpy, J/kg |
| $\dot{m}$ | Mass flow rate, kg/s |
| P | Pressure, bar |
| s | Absolute entropy, J/kg K |
| T | Temperature, K |
| w | Uncertainty, % pfs or absolute |

*Acronyms*

| | |
|---|---|
| IEC | International Electrotechnical Commission |
| LHV | Lower Heating Value |
| MW | Mega Watt electricity |
| PFS | Percent Full Scale |

*Greek Symbols*

| | |
|---|---|
| $\eta$ | Energy efficiency |
| $\zeta$ | Exergy efficiency |

*Subscripts*

| | |
|---|---|
| s | Isentropic |
| 1 | Inlet state of HPT |
| 2 | Outlet state of HPT |

*Superscripts*

| | |
|---|---|
| 0 | Reference state value |

power plant [4]. They have conducted an uncertainty analysis for energy efficiency of 160 MW coal fired power plant through comparing Monte Carlo, Fourier transform and differential methods. They have indicated that the evaluating plant efficiency is strongly related to measurement of plant operation and it is essential for plant management to understand and know which measurements are most critical and how accurate they need to be within the context of maintenance and modernization decisions. Moran defines turbine effectiveness that is a parameter that gauges how effectively the turbine converts the exergy flow into work [5]. The parameter defined is a kind of exergy efficiency; however, no uncertainty calculations have been presented in the accompanying examples. Nord et al. have incorporated uncertainty analysis in modeling of integrated reforming combined cycle [6]. They have concluded that parameters with the largest impact on uncertainties of power output and efficiency predictions are proved to be gas turbine inlet temperature, and compressor and turbine efficiencies. Şahin and Ege have discussed chemical exergy methods and its effects on power plant's exergy efficiency calculation [7]. They conclude that unlike the case for energy efficiency, exergetic efficiency of a certain large scale thermal power plant varies from the average exergy efficiency between −2.08% and 4.29% depending on the chemical exergy determination method employed for the lignite. Ege and Şahin studied energy and exergy efficiency uncertainties as well as various measurement parameter sensitivities of a large scale thermal power plant [8]. It was concluded that Lower Heating Value (LHV) determination was found to be the most important uncertainty source of energy and exergy efficiency of the plant according to the black box method defined in the paper. Siefert and Litster, on the other hand, presented exergy and economic analyses of two advanced fossil power plant configurations. Rather than thermodynamic uncertainties they account for uncertainties in economical parameters such as capital costs, operation and maintenance costs and $CO_2$ sequestration costs [9]. Wang et al. point out uncertainties associated with cost functions in their multi-objective optimization of coal fired power plants [10]. As they indicate the largest uncertainty is introduced by temperature related and reheat related cost coefficients of the steam generator.

In the literature there are several papers available on energy and exergy analysis of power plants and their components. However, none of them have used uncertainty analysis of energy and exergy efficiency for their studies. Therefore, this study focuses on analysis of the uncertainties in isentropic and exergy efficiency of HPT of a lignite-fired power plant. Furthermore, performance of the extreme cases measurements analysis has been studied. Ege and Şahin have studied the uncertainties of the cycle efficiency of a lignite fired power plant through the investigation of uncertainties in electricity output, coal mass flow rate and coal lower heating value measurements and calculations [8]. Whereas, this study is more concentrated on HPT isentropic and exergetic efficiencies by analyzing uniquely derived uncertainty terms for a turbine.

## Materials and methods

### *Uncertainty analysis*

#### *Background*

In order to calculate the uncertainty of the efficiency of HPT efficiency function F is considered as a function of independent variables $x_1, x_2, x_3 \ldots\ldots, x_n$ [11] as the following:

$$F = F(x_1, x_2, x_3 \ldots\ldots, x_n) \tag{1}$$

The uncertainty in the result would be a function of independent variables ($w_1$, $w_2$ … $w_n$ are the uncertainties in the independent variables) yielding [11],

$$w_F = \left[\left(\frac{\partial F}{\partial x_1} w_1\right)^2 + \left(\frac{\partial F}{\partial x_2} w_2\right)^2 + \ldots + \left(\frac{\partial F}{\partial x_n} w_n\right)^2\right]^{1/2} \tag{2}$$

Equation (2) should be expressed with the same odds. If the F function given above is in the form of product of variables,

$$F = x_1^{a1} x_2^{a2} \ldots x_n^{an} \tag{3}$$

then the uncertainty is given by Equation (4)

$$\frac{w_F}{F} = \left[\sum \left(\frac{a_i w_{x_i}}{x_i}\right)^2\right]^{1/2} \tag{4}$$

However, if the same function indicated in (1) has an additive form:

$$F = a_1 x_1 + a_2 x_2 \ldots a_n x_n \tag{5}$$

the uncertainty in this case is simply given by

$$w_F = \left[\sum (a_i w_{x_i})^2\right]^{1/2} \tag{6}$$