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Review

Malfunction diagnosis of thermal power plants based on advanced exergy analysis: The case with multiple malfunctions occurring simultaneously

Ligang Wang[a,b,c,*,†], Peng Fu[a,d,†], Ningling Wang[a], Tatiana Morosuk[b], Yongping Yang[a,*], George Tsatsaronis[b]

[a] National Research Center for Thermal Power Engineering and Technology Research Center, North China Electric Power University, Beinong Road 2, Beijing 102206, China
[b] Institute for Energy Engineering, Technical University of Berlin, Marchstraße 18, Berlin 10587, Germany
[c] Industrial Process and Energy Systems Engineering, Swiss Federal Institute of Technology in Lausanne, Rue del'Industrie 17, Sion 1951, Switzerland
[d] Shenhua Guohua (Beijing) Electric Power Research Institute, Chaoyang district, Beijing 100025, China

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ABSTRACT

During continuous operation of energy systems, the performance of components will mostly, gradually deviate away from the reference conditions due to performance degradation, which may eventually lead to malfunctions or operation failure. The complex interconnection among components and the propagation nature of additional irreversibility caused by malfunctions increase the difficulty of malfunction diagnosis. Particularly, in common real-world cases, multiple malfunctions usually happen simultaneously in several different components, imposing additional difficulty for effective malfunction identification and quantification. In this paper, we generalize an effective diagnosis method recently proposed by the authors to accurately locate the malfunction component and quantify the effect caused by anomalies of multiple malfunctions. The generalized method is based on advanced exergy analysis, where exergy destruction within each component is split into endogenous and exogenous parts. The endogenous exergy destruction is due to the irreversibility of the component itself, while the exogenous is caused by the inefficiencies of the remaining components. The exogenous exergy destruction is, in fact, the major obstacle to accurately pinpoint the origins of performance degradation. In the generalized approach, an internal exergy indicator is recommended to be applied first to identify the malfunction components in a fast and effective manner. Then the endogenous exergy destruction of the identified malfunction components under the reference and degradation conditions is calculated and compared for accurate quantification. The generalized diagnosis approach is applied to a complex real-world case studies, in which several malfunctions are introduced simultaneously into different components. The results show that the proposed indicator could fast identify the source of anomalies while the endogenous exergy destruction successfully and effectively quantifies all introduced malfunctions.

Contents

* Corresponding authors at: Swiss Federal Institute of Technology in Lausanne, Switzerland (L. Wang). North China Electric Power University, China (Y. Yang).
E-mail addresses: lgwangeao@163.com (L. Wang), yypncepu@163.com (Y. Yang).
† These authors contributed equally to the work.

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Nomenclature

HP	high-pressure turbine	*h*	specific enthalpy, kJ/kg
IP	intermediate-pressure turbine	*e*	specific exergy, kJ/kg
LP	low-pressure turbine	*s*	specific entropy, kJ/(kg K)
CON	condenser	$\dot{m}$	mass flow rate, kg/s
H*n*	the *n*th heater	$\dot{E}$	exergy rate, MW
DEA	dearator	$\dot{E}_D$	exergy destruction rate, MW

Greek symbols

α	performance parameter
ζ	internal exergy parameter
ε	exergy efficiency
θ	internal parameter
η	Isentropic efficiency

Mathematical symbols

f	function capturing the endogenous exergy destruction

Subscripts and superscripts

k	the *k*th component
in	inlet
out	outlet
EN	endogenous
EX	exogenous
REF	reference state
MAL	malfunction state

1. Introduction

Nowadays, coal still plays a significant role in worldwide energy mix. Coal recoverable reserves are estimated around 17 billion metric tons in January 2013 and expected to last for about 113 years with the current coal consumption rate, even no more recoverable reserves are found in the future [1]. In China, thermal power generation, mostly from pulverized-coal fired power plants, is and will still be the major pillar for power generation, even with an increasing penetration of renewable energy installed recently. The shares of installed and generating capacities of thermal power have been reduced but still remained at 67.2% and 72.3% by the end of 2015 [2]. Considering the high emission of many pollutants and greenhouse gases from coal combustion, strict environmental regulations have been imposed to coal-fired power plants. Since pollutant removal and CO_2 capture are mostly cost- and energy-intensive, the most straightforward measure is to improve and maintain high energetic performance of thermal power plants all over the operation period [3]. As a result, the average specific coal consumption of coal-fired power plants has been reduced dramatically by 71 g/kWh from 385 g/kWh in 2001 to 314 g/kWh in 2015 [4].

Maintaining high efficiency and plant reliability during operation is a key factor to ensure continuous, non-stop operation. Actual operation performance of power plants mostly differs from the original design performance, due to component degradation and anomalies during normal operation, which eventually result in an increase in the specific coal consumption [5] or a decrease in the overall system efficiency [6]. Therefore, it is important to identify accumulated performance degradation or possible anomalies in time before large performance deviation or operation interruptions occur. To cope with these issues, energy diagnosis is frequently performed during operation, which aims at the identification of malfunction sources [7] and the quantification of malfunctions [8]. The identification of malfunction causes helps find the components with high possibility of operation failures [9], which is essential for efficiently proposing effective maintenance interventions [10]. Quantifying malfunction effects indicates the increment of the amount of resources required to obtain the same product with the same operating boundaries but different component states [11].

Current available diagnosis approaches for plant reliability improvement are simply based on the comparison of fuel consumption or efficiency between the actual and reference plant states [12]. However, such a simple comparison ignores the fact that the malfunction of a component is a consequence of accumulative continuous degradation process rather than a sudden accident. The performance degradation leads to a deviation of performance from the original reference state, represented typically by an increase in the specific fuel consumption. The degradation is accumulated during operation and eventually results in a component malfunction. Note that the components with malfunctions may still work but they generally have larger possibility than healthy components leading to operation failures. From such a perspective, if the performance diagnosis can identify the origins of malfunction in a fast and accurate manner, it will be capable of forecasting possible failures and thus protecting components from operation failure.