Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-7 (2016) 353–358

Energy-based Fault Detection for an Autothermal Reformer

Henri-Jean Marais, George van Schoor, Kenneth R. Uren

School of Electrical, Electronic, and Computer Engineering. North-West University, Potchefstroom, North-West Province 2531, South Africa (e-mail: henri.marais@nwu.ac.za).

Abstract: Condition monitoring has traditionally been deployed for the monitoring of a single component, such as a rotating machine. The application of condition monitoring techniques to entire petrochemical process plants, however, remains lacking. This can be ascribed to the significant complexity involved in applying existing techniques to such plants. In this work a novel energy-based fault detection scheme is applied to an autothermal reformer of a gas-to-liquids process. The performance of the technique is evaluated, against a set of representative faults, and it is shown to provide adequate fault detection performance. The use of the energy-based detection scheme shows promise in terms of reduced modelling efforts and increased computational efficiency.

Keywords: Condition Monitoring, Energy, Process, Industrial, Fault Detection

1. INTRODUCTION

It is a well-known fact that the world is facing an energy crisis, and that this crisis is mainly due to depletion of fossil fuel resources. Although this has spawned many research efforts into alternative energy sources, it has also prompted research into more energy efficient processes. Traditionally the efficiency of a process could be maximised by improving the control scheme or by upgrading the process technology. However, for certain industrial processes this is simply not feasible as the improvement that can be obtained is overshadowed by the significant process risk incurred in doing so. As a typical example consider a petrochemical plant. Upgrading of the control technology is estimated by White (2010) to yield an improvement of less than 5%, whilst there is little that can be done to the underlying technology used to implement the process.

When one considers the entire operational environment of such a plant, the maintenance processes become interesting. Time-based methods can provide high-reliability systems (often at excessive costs) and also assumes that equipment failures will occur at fixed time intervals according to Kothamasu et al. (2009). Although not all of the key components being replaced necessarily *needs* to be replaced, the risk (and associated costs) associated with a component failure simply exceeds the replacement cost of said component.

Several alternative strategies to time-based maintenance exist, and of these, risk-based maintenance (RBM) and predictive maintenance (PM) are the most common as per the review by Jardine et al. (2006). Although Foldvari (2012) estimates that cost savings could be as high as 20%-40%, widespread adoption of RBM or PM remains lacking.

One likely reason for this is the fact that an accurate estimation of component failure probability must be provided. The first step towards providing these estimates is determining the current condition of the component.

In section 2 we provide some relevant background, with a more detailed discussion of the applied technique in section 3. In section 4 we develop a simple model of an autothermal reformer, and also list some representative faults. The resulting performance of the fault detection technique is presented in section 5 and a discussion of the suitability of the technique follows in section 6. Concluding remarks and further work are presented in section 7.

2. BACKGROUND

2.1 Condition monitoring

Historically condition monitoring has its roots in the monitoring of large scale industrial machines, typically rotating machines according to a review by Jardine et al. (2006). In recent years, condition monitoring has also been applied to other electrical machines, such as transformers and switch mode power supplies (Yang et al. (2010)). However, when one attempts to find applications of condition monitoring in the process industries (beyond electrical machines within process plants as was done by Almasi (2011)), scarcely any published works can be found.

Fundamentally, condition monitoring can be considered as a classification problem. A signal (or signals) of interest is measured, submitted to a diagnostic algorithm, and finally to a prognostic algorithm to determine the effect of the diagnosis on the overall condition of the component. The diagnostic functions are primarily concerned with determining the current state of the monitored system, for which artificial neural networks (ANNs) are most commonly used according to Venkatasubramanian et al. (2003). Prognostic algorithms aim to provide a future state estimate of the system, based on current system information. However,

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.325

in a review by Peng et al. (2010) current research efforts with regards to prognostic algorithms have been shown to present less than stellar results. The high variability in the accuracy of prognostic algorithms makes these algorithms a largely academic interest at current.

If one disregards prognostics, there is a large correlation between the fields of condition monitoring and fault detection and identification. The area of fault detection and diagnosis (FDD) is primarily concerned with the detection, and diagnosis (insofar as location and magnitude are concerned) of fault conditions. Gertler (1998) considers fault detection and diagnosis to be more complete than fault detection and isolation (FDI) schemes (see Figure 1), as the magnitude of faults can also be detected by FDD schemes.

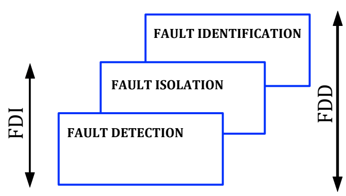

Fig. 1. Comparison of FDI and FDD

2.2 Fault detection and isolation

In Figure 2 a classification of various common fault detection schemes is presented (based on the work of Venkatasubramanian et al. (2003)). Broadly, fault detection methods can be classified as either being of the model-based or model-free type. In model-free detection schemes an explicit model is unavailable, and only process history data is used for fault detection. Typically detection is accomplished using statistical techniques which offers fast detection capabilities, but isolation and identification of faults are significantly more difficult. The main disadvantage of the model-free methods is the large labelled historic database that is required.

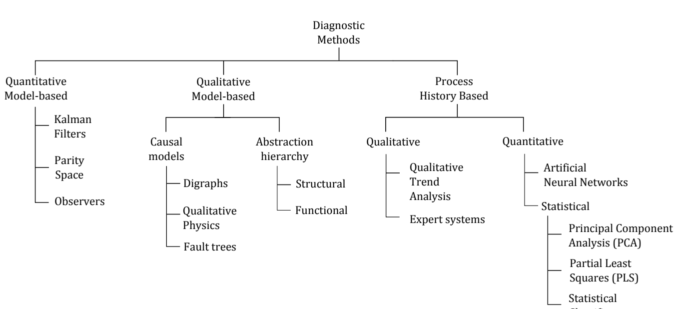

Fig. 2. Diagnostic method classification

The model-based methods require a model of the process. In the quantitative sphere, these models typically take the form of analytical or differential equations. Analytical models have the advantage of generally being more accurate, and the modelling fidelity can be adjusted according to the specific monitoring requirements. However, the major disadvantage of analytical models, as identified by Juslin et al. (2005) is the high degree of complexity inherent in the process, as well as the amount of time required to construct even a relatively simple model. For industrial chemical processes, the derivation of analytical models are widely considered to be either too complex or too costly to be feasible.

Qualitative model-based methods make use of qualitative modelling techniques such as qualitative physics, or simple signed directed graphs and can be seen as a compromise between analytical rigour and ease of implementation. No single FDI technique will be equally applicable to all problem domains and Venkatasubramanian et al. (2003) argues that a hybrid approach will likely provide optimal FDI performance. If one considers hierarchical decomposition schemes the main advantages are an improvement in the performance of the classifier (less complex) as well as a decoupling of process units. The latter has been identified by Jardine et al. (2006) as a critical area for improvement.

2.3 Energy as modelling domain

The need for multi-domain modelling techniques is not new and was identified in early works by Chinneck and Chandrashekar (1984). Since energy is a well defined, multi-domain concept, it poses the question, whether energy can be used as the monitoring domain? Theoretically this would:

- Reduce the input space to a single dimension;
- Allow for hierarchical monitoring;
- Provide inherently multi-domain models.

Consider a generalised *energy model* of a unit operation (see Figure 3).

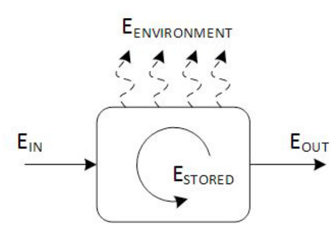

Fig. 3. Generalised energy model of unit operation

Since only a single parameter domain is concerned (energy) various unit operations can be coupled together to form a process. Additionally, a process can be simplified to a single model block with the various energy flows simply being the algebraic sum of each unit operation's energy flows. Interestingly, by modelling the problem space in the energy-domain, model reduction is achieved whilst maintaining a large degree of similarity between the *energy model* and the physical process plant.

3. ENERGY-BASED FAULT DETECTION

Du Rand et al. (2009) developed a method that allowed condition monitoring of a nuclear-powered closed Brayton cycle, by monitoring the entropy s, and enthalpy h, at each point in the cycle. Effectively this transforms the measurement space into an energy domain. This transformation reduces the input space to only two dimensions, which is computationally more efficient, and allows a simple diagram (see Figure 4), referred to as the entropy-enthalpy graph by Du Rand and Van Schoor (2012a), to