Journal of Loss Prevention in the Process Industries 54 (2018) 1–9

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

A multi-setpoint delay-timer alarming strategy for industrial alarm monitoring☆

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ARTICLE INFO

Keywords:
Alarming strategy
Markov processes
Delay-timer
False alarm rate
Missed alarm rate
Averaged alarm delay

ABSTRACT

Alarm systems play an important role in industry to notify operators of abnormal and fault situations. In real industrial plants, however, a majority of abnormal alarm phenomena, including false alarms and missed alarms, always interfere with operators' judgment. Mathematical analysis of traditional univariate alarm techniques indicates that the alarm setpoint, the dynamic alarm order, and the alarm algorithm are the three main elements of alarm annunciation and alarm clearance. Based on this, we proposed a multi-setpoint delay-timer alarming strategy which optimizes the false alarm rate (FAR), the missed alarm rate (MAR), and the averaged alarm delay (AAD) by increasing the number of univariate alarm setpoints. The proposed alarming strategy is able to achieve a balance between alarming accuracy and alarming sensitivity. Its effectiveness is demonstrated with both simulation and industrial case studies.

1. Introduction

In large modern industrial plants, abnormal situations could not only affect plant efficiency, but also bring safety risks, major accidents, and even disasters, eventually leading to heavy casualties and economic losses. According to statistics by the Abnormal Situation Management (ASM) Consortium, the amount of economic losses caused by abnormal plant situations in the petrochemical industry in US is about 10–20 billion dollars per year, and a major accident occurs every three years on average. A typical case is the nuclear power accident occurred at Three Mile Island in 1979, known as the worst nuclear accident in the US history. Alarm systems, as an effective means to detect and report abnormal operation situations, can assist operators in identifying root causes and making proper response immediately. Thus they play an irreplaceable role in ensuring operation safety and plant efficiency.

The design of alarm systems has attracted great attention from both academia and industry and becomes one of the emerging research fields in the process control and automation community in recent years (Wang et al., 2016; Izadi et al., 2009). Two categories of alarming strategies are commonly used in real industrial alarm systems, namely, univariate alarming strategies and multivariate alarming strategies. Fig. 1 shows the classification of some prevalent alarming methods.

Univariate alarming methods are widely employed in practical alarm systems due to their convenience in design and implementation, and the alarm information they provide based on the signal of a single process variable is clear and propitious to operators' decision-making. The threshold-based alarming strategy is the most common univariate method which has a single order (i.e., only the current status is considered) and a single fixed alarm setpoint, and identifies the alarm status by comparing real-time data with the fixed setpoint. The simplicity of this method brings its massive applications in real alarm systems but limits its employment in complex alarming circumstances. Methods with moving window techniques or multi-setpoint settings are designed to meet higher alarming requirement. Moving window alarming settings denote that the alarm status is obtained by a function transformation of several measured values and alarm statuses in the past. Methods of this kind include the alarm delay-timer and the alarm filter (Cheng et al., 2013; Xu et al., 2012; Adnan et al., 2011; Kondaveeti et al., 2011). Multi-setpoint settings denote that the alarm annunciation and the alarm clearance of an alarm status correspond to different setpoints. A typical example is the alarm deadband which usually uses two setpoints to form the deadband (Adnan et al., 2013).

In contrast to univariate methods, multivariate approaches are more suitable for alarm management in cases where the relationship between process variables are rather complicated. These approaches are believed to have good performance in reducing the alarm number,

☆ A preliminary version of this paper was presented as H. Zang, F. Yang, D. Huang, "Design and analysis of improved alarm delay-timers", in the proceedings of the 9th International Symposium on Advanced Control of Chemical Processes, Whistler, BC, Canada, June 2015.

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https://doi.org/10.1016/j.jlp.2018.02.004
Received 22 November 2017; Received in revised form 15 February 2018; Accepted 15 February 2018
Available online 26 February 2018
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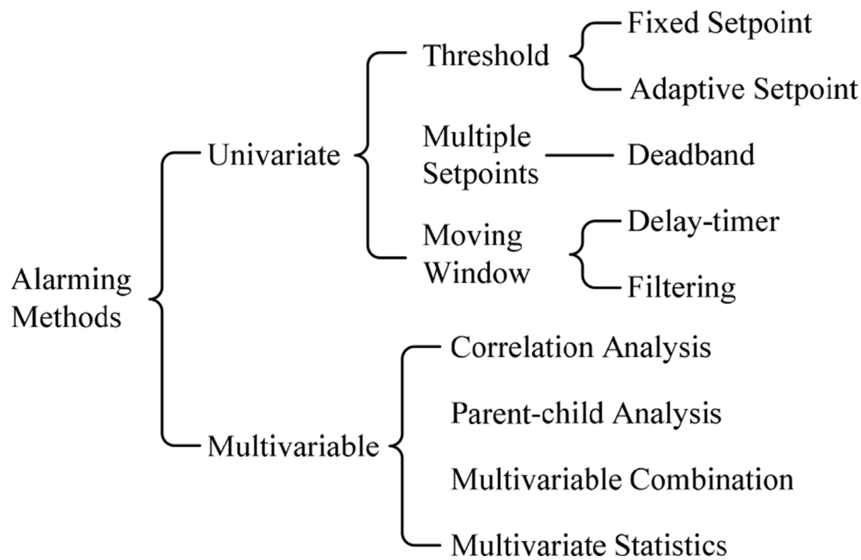

Fig. 1. Classification of alarming strategies.

shortening the alarm delay time, and inhibiting alarm floods (Schleburg et al., 2013; Ahmed et al., 2013). For example, correlation analysis and parent-child analysis based on process knowledge and process data are fundamental tools in advanced alarm management systems (Yang et al., 2012a, 2012b). Methods through multivariable combination and multivariate statistical analysis can generate integrated alarms that indicate the plant-wide abnormal status in a system level (Zhu et al., 2014; Kondaveeti et al., 2012). In spite of the merits of multivariate approaches, a non-negligible problem is that they require in-depth understanding of the whole process, which seriously limits the scope of their application (Yang et al., 2013).

The objective of the alarming strategy design is to achieve high alarming accuracy and fast detection speed. According to industrial standards such as ISA 18.2 (International Society of Automation, 2016) and EEMUA 191 (Engineering Equipment and Materials Users' Association, 2013), the embodiment of most applied alarm systems cannot well meet the practical requirements of alarming sensitivity and alarming accuracy. In particular, false alarms and missed alarms in current alarm systems should be further reduced to keep alarms reflecting real conditions, and alarm delays also need effective reduction to help operators make rapid response after the occurrence of plant faults. In view of these problems, this paper will present a new delay-timer alarming strategy in the univariate framework to improve alarming accuracy and alarming sensitivity. The proposed strategy increases the number of univariate alarm setpoints and is proved to outperform some other univariate methods in terms of the false alarm rate (FAR), the miss alarm rate (MAR), and the averaged alarm delay (AAD).

The rest of the paper is organized as follows. The mathematical analysis of some classical univariate alarming strategies is introduced in section 2. The conventional delay-timer is discussed in section 3. In section 4, the multi-setpoint delay-timer method is proposed and explained in details. Simulation and industrial case studies are provided to demonstrate the advantages of this method in section 5, followed by concluding remarks in section 6.

2. Classical univariate alarming strategies

2.1. Basics of alarming strategy

In the process industry, five alarm statuses are typically configured in alarm systems, namely, low-low alarm, low alarm, non-alarm, high alarm and high-high alarm. Switches among these statuses correspond to two alarming processes, alarm annunciation (the transition from the non-alarm status to the alarm status) and alarm clearance (the transition from the alarm status to the non-alarm status). For explanation simplicity, we focus on the switches between the non-alarm status (denoted by '0') and the high alarm status (denoted by '1') in this section.

Two main indicators, the false alarm rate (FAR) and the missed alarm rate (MAR), are commonly employed for evaluating alarming strategy performance. Fig. 2 shows the annunciation mechanism of false alarms and missed alarms, where X_T is the alarm setpoint. When the system is in normal condition, the value of the process variable may exceed X_T, resulting in the generation of a false alarm; if the system is in abnormal status, the value of the process variable may return to the region below X_T, and subsequently a missed alarm is generated. For simplicity, process variables involved in the following are assumed to be independent and identically distributed (i.i.d.) (Wang et al., 2016; Izadi et al., 2009). The receiver operating characteristic (ROC) curve is used to represent the relationship between FAR and MAR. As shown in Fig. 3, there is always contradiction in the control of FAR and MAR (Kondaveeti et al., 2011).

2.2. Threshold-based alarming

The threshold-based alarming is commonly considered as the most basic alarming strategy. It can be set conveniently in most of distributed control systems (DCSs). The alarm status in the threshold-based alarming is determined through the comparison of the real-time process

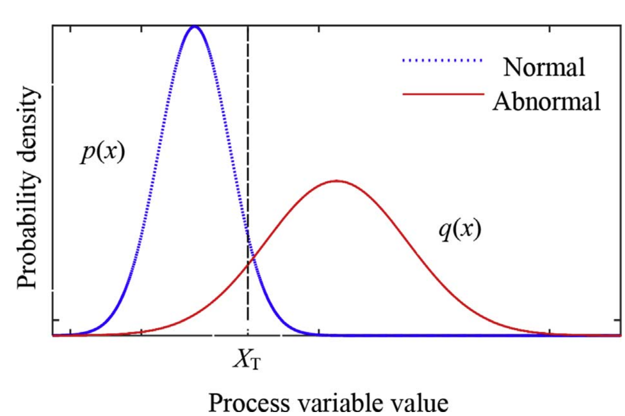

Fig. 2. Probability distributions of a process variable in normal and abnormal conditions.