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On the use of penalty approach for design and analysis of univariate alarm systems

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ABSTRACT

Alarm systems indicate abnormal conditions of the underlined plant equipment enabling operators to take corrective actions, and bring the equipment back to its normal condition. This paper presents a new approach for designing a generalized delay timer based on the *penalty* scenario and Markov chain schemes. The *penalty* approach is an extension for the well-known “n-sample on/off delay timer” approach in designing alarm systems. Three performance indices named, False Alarm Rate (FAR), Missed Alarm Rate (MAR) and Average Alarm Delay (AAD) are derived for the proposed *penalty* approach using Markov theory. Also, a new index named “Mean Time to Alarm (MTTA)” is introduced to analyze the underline alarm system, and to compute AAD. Finally, the effectiveness of the proposed method is investigated and compared with that of the other methods through a case study.

1. Introduction

Control systems, either conventional control desks or computers/PLCs with Supervisory Control and Data Acquisition (SCADA) unit provide a human-machine-interface (HMI) to monitor and control processes. Alarm systems as an integral part of human-machine- interface equipment consist of both hardware and software units. These include field signal sensors, transmitters, alarm generators and handlers, alarm processors, alarm displays, annunciator window panels, alarm recorders, and printers. Alarm systems indicate abnormal conditions of the underlined plant equipment enabling operators to take corrective actions, and bring the equipment back to its normal condition. The design of an optimal alarm system is an important issue to facilitate accurate and timely prompting, and diagnosing faults, and hence more effective plant management. Alarm floods (the occurrence of an excessive number of alarms during the abnormal situation) should be carefully studied in the investigation of major plant accidents. During the design process, default attributes (such as set points, dead bands, filters and timing delay [1,2]) should be defined for each alarm.

In the last decade, advanced alarm management systems and precedence analysis for process plants have received increasing attentions from both industrial and academic communities. In [3], a methodology is introduced to remove nuisance alarms, a so-called cleanup. In [4], a new mathematical treatment policy of alarms (that considers them as multi-variable interactions between process variables) has been introduced. Paper [5] used the time series analysis approach to determine time alarm deadbands. The paper showed that the optimal value for deadband can be determined by both measurement noise and the trajectory of the signal immediately preceding the alarm. Reference [6], formulated the detection of chattering alarms based on the alarm durations and intervals. In [7], an intelligent alarm management system for suppressing nuisance alarms is developed. The paper provided an advisory information to help operators to focus quickly on important alarm information, and to take a quick action. Some basic univariate statistical process control (SPC) concepts such as “moving average” and “standard deviation” are used in [8] to estimate the variation of the monitored process variables in real time. A new approach for filtering faults is presented in [9] thanks to the dynamic fault tree (DFT) concept. In reference [10], the issue of detection delay for moving average filters is computed. Paper [11] made a further attempt on optimal alarm filter design, and performed an analysis on the relationship between the moving average filters and optimal Finite Impulse Response (FIR) linear filters. In [12], a formula is derived to estimate chattering from distribution characteristics of process data. The procedure is based on the probability analysis of

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alarms. The concept of "run length" is used to quantify the degree of alarm chattering [13].

In addition to deadbands and filters, delay timers are other useful tools to reduce nuisance alarms. In [14], a systematic approach is presented for alarm design based on a n-sample on/off delay timer (we will call this timer as "reset scenario" in the remaining parts of this paper) using Markov scheme. Paper [15] proposed a generalized delay-timer framework and introduced the n_1 -out-of-n scenario to raise and clear an alarm. In [16], detection delays were calculated by using Markov process theory for deadbands and delay timers. Reference [17] proposed a new method by considering the internal relationship between no-alarm rate and alarm rate to compute the FAR, MAR and Expected Detection Delay (EDD) indices using Markov chains.

In recent years problems like multivariate alarming and decision-making methods have been highlighted by a number of researchers. Paper [18], suggested a new method for optimizing multivariate alarm thresholds based on FAR, MAR and correlation analysis. In [19], T^2 and Q -Statistics are used for detecting additive and multiplicative faults in multivariate statistical process monitoring. In [20], "Evidence Theory" is used for designing optimal alarm systems. Issues like causes of "nuisance alarm", and design methods of alarm systems have been reviewed in [21]. Some research works have studied Fault Tolerant Control (FTC) problem for Markovian Jump Systems. Reference [22] studied the stabilization problem for nonlinear Markovian jump systems with output disturbances. Reference [23] investigated the state estimation and FTC problems for a class of Markovian jump systems with external disturbance and sensor faults. In [24], a novel sliding mode observer is developed to solve the FTC problem for stochastic systems with Markovian jump parameters.

According to ISA standard [1], various types of key indices are used for analysis of alarm performance of which "average annunciated alarm rate" and "peak annunciated alarm rate" can be stated. Also, False Alarm Rate (FAR), Miss Alarm Rate (MAR) and Average Alarm Delay (AAD) are other widely used indices for alarm management [14].

In this paper, a new scenario for designing delay timers is presented based on a novel concept named here "penalty" concept. Penalty scenario is a generalized case of the n-sample on/off delay scenario [14]. The paper formulates indices for general case of penalty scenario using the Markov scheme. Index AAD is computed based on a new index named here "Mean Time to Alarm (MTTA)", for penalty scenario. In the sense of performance, it has been proved that indices FAR, MAR and AAD in penalty scenario give better results compared with the reset scenario for $2 \le i < n-1$. A numerical example and an industrial case study are also provided to illustrate the effectiveness of the proposed method.

This paper is organized as follows. Section 2 introduces the problem and alarm indices. In sections 3, two existing scenarios for delay timers are studied. Section 4 introduces the proposed novel scenario. Section 5 devoted to computation of alarm indices for penalty approach. A comparison between the performance of various scenarios is carried out by a number of case studies in Section 6. Finally, some concluding remarks are given in Section 7.

2. Performance measurement of the basic alarm system

2.1. Markov process

A Markov process is an independent process for which the outcome at any time instant depends only on the outcome that precedes it. In this paper, the Markov process is used to compute alarm indices. Assume that transitional probability, p_{ij}, is the probability of moving from state e_i at time t to state e_j at time $t+1$. Define the transition probability matrix as the following:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1j} & \cdots \\ p_{21} & p_{22} & \cdots & p_{2j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ p_{i1} & p_{i2} & \cdots & p_{ij} & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

A probability vector π is called invariant for a Markov process if $\pi = \pi P$. An invariant vector π exists if the Markov process satisfies the following conditions [16]:

1 The sum of all entries in each row of P is 1.
2 All the entries of P are non-negative.

To satisfy these conditions, we make the following assumptions on the process data [16].

1 Process data is Independent and Identically Distributed (I.I.D.), i.e., at each sampling time, the process data has the same probability distribution as the other time instants, and all are mutually independent.
2 Probability density functions of the fault free and faulty data are known. These distribution can be estimated from the historical data.

2.2. Performance indices

This sub-section introduces performance indices, FAR, MAR and ADD for basic univariate alarm system. A "false alarm" is an alarm that is raised incorrectly when the process behaves normally, and "miss alarm" occurs when the process behaves abnormally without raising alarm is raised. Consider a hypothetical discrete process data with sampling time h illustrated in Fig. 1(a). For basic alarm generation method [14], an alarm is raised if $x(t)$ exceeds alarm trip point x_{tp}. Assume that a fault is occurred at time, $t = 1000h$, where $h = 1\,sec$, then normal and abnormal parts of the process variable are $x(1:1000)$ and $x(1001, 2000)$, respectively. In the fault-free operating region, assume that the probability that a unique sample exceeds the alarm limit is q_1, and the probability of falling a unique sample from the alarm limit, in the faulty region of operation, is p_2. The Probability Density Functions (PDFs) of normal and abnormal data can then be achieved according to Fig. 1(b). The index False Alarm Rate (FAR) is then defined as below.

$$FAR = q_1 = \int_{x_{tp}}^{+\infty} q(x)dx \tag{1}$$

Also, the probability of Missed Alarm Rate (MAR) extracted from $p(x)$ of Fig. 1(b) can be defined as follows:

$$MAR = p_2 = \int_{-\infty}^{x_{tp}} p(x)dx \tag{2}$$

Another index in alarm performance analysis is the Average Alarm Delay (AAD). Suppose that a fault occurs at time t_0 and the related alarm raised at time t_a. Then $T_d = t_a - t_0$ denoted the alarm delay. It is obvious that T_d is a discrete random variable with sample space $\{0h, 1h, 2h, \ldots\}$. Hence AAD is defined as the expected value of T_d.

$$AAD = E(T_d) \tag{3}$$