Abnormal Situation Management: a Process Dynamics Approach

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Abstract:

Abnormal situations are events that are outside of normal plant operating modes. It is estimated that the U. S. economy could reduce costs by $20 billion per year by avoiding abnormal situations. Modern control systems can provide advanced warning for potentially abnormal conditions, thus alerting process operators to take appropriate actions. However, alarm limits are chosen by empirical procedures, which have been proved ineffective or insufficient in some control systems, such as the control system of a continuous exothermic reactor. Dynamic modeling of processes integrated with control systems can provide operators with early awareness of abnormal situations, direct the design of multi-variable alarm/shutdown systems, and help to choose appropriate alarm/shutdown limits.

Stochastic methods, such as statistical analysis and artificial neural networks, are other tools for abnormal situation management. As a supplement to process dynamics analysis, stochastic methods have the ability of heuristic causal reasoning, which can help to analyze unnoticed variables in dynamics analysis.

Introduction

Abnormal situations are events that are outside of the desired operating conditions and are generally characterized by the following symptoms[1]:

- Alarm flooding
- Protective systems operation
- Use of rarely used operating procedures
- Accidents, such as leaks, fires, and explosions

Although most abnormal situations do not result in serious accidents, such as fires and explosions, they cause poor product quality, schedule delays, equipment damage, and other costs. The Abnormal Situation Management (ASM) Joint Research and Development Consortium (consists of major petrochemical companies, software developers, and led by Honeywell) reported that abnormal situations cost the U.S. more than $20 billion annually, of which about $10 billion was from the petrochemical industries[2]. Estimates indicate that elimination of all abnormal situations in the petrochemical industry could add 5% to profits[3].

Process Dynamic Modeling

Chemical plants use programmable control systems such as distributed control systems (DCS), programmable logic controllers, and supervisory control and data acquisition systems to control simultaneously thousands of process variables, such as temperature, pressure, and liquid level. In addition, modern instrumentation and control systems assign a variety of alerts, warnings, and alarms on sensor values and initiate appropriate action if the alarms are ignored, thereby permitting process operators to avoid, delay, or rectify the situation that is trending to undesirable conditions.

Traditionally, alarms were set at some upper limits to warn operators of impending out of range conditions. Higher-level shutdown alarms were set to bring processes to safe states without process operator intervention. Generally, these alarm limits were chosen by empirical or WAG procedures without analyzing the potential dynamics of the process conditions. Recent advances in dynamic process modeling can be used to provide more intelligent selection of alarm limits.

In the 1990s, advances in chemistry made possible complex compounds and reactions that require more complex control algorithms, such as fuzzy logic, artificial neural network, and adaptive control. At the same time, the chemical process industry has continued to upgrade safety-instrumented systems (SIS). While control system providers have been incorporating advanced control technologies, similar sophistication has yet to reach most safety-instrumented systems. A common example is that operators still receive a low flow alarm when s/he stops the corresponding feed pump. Within normal operating range control, process automation has permitted the application of multivariable control schemes. However, SIS, including both alarm and shutdown systems, have simply replicated traditional alarm settings, and multivariable alarm and shutdown systems are rare. Although control system capabilities exist to consider dynamic process modeling, the application of process dynamics to operator alarm conditions has been rare.

A common example of ineffective alarms is the high temperature alarm and shutdown systems for flue gas. Many of these systems have temperature sensors placed too far downstream for operators to react to a rapid temperature rise, resulting in expensive equipment damage. Also start-up of a fired heater/boiler has some traditional interlocks (per NFPA 85) that may not be appropriate unless sufficient information is provided to the operator. In oil/gas separators, sand build-up can impact the dynamics of the alarm and shutdown system. Quantifying these dynamics is critical to maintaining effective abnormal situation management. Another example of the need for multivariable dynamics is the continuous exothermic reactor, such as polymerization reactors. Loss of cooling water typically closes the feed supply valves. Many dynamic water supply conditions or failure of the alarm/shutdown logic solver can result in a reactor runaway.

Dynamic modeling of the reactor, chemical supply, utilities, and control system can provide operator with early awareness of pending abnormal situations, direct the design of multi-variable alarm/shutdown systems, and help to choose appropriate alarm/shutdown limits. More-complex solutions involving dynamic simulators and fault trees may change the control and operations from reactive to predictive and preventative.

Stochastic Methods

The continued validity of the alarm system depends on no change to the process dynamics and the SIS dynamics. In reality, process dynamics can change. A statistical analysis can assist in identifying growing deviations from previous operating conditions and reveal directly unobservable factors.

An example of information that can be derived from the massive amount of data captured by a modern DCS is the slow changes in distillation columns or heaters caused by solids buildup. While the impact of solids buildup cannot be measured directly, it can be inferred from the trend analysis. Recently, the solids buildup in a chlorine purification distillation tower caused changes in the liquid holdup on the trays of the column and consequently increases the concentration of nitrogen trichloride and column temperature. Eventually the nitrogen trichloride concentration rose to dangerous levels and eventually exploded. A trend analysis could have alerted the operators to potentially dangerous nitrogen trichloride concentrations.

Artificial neural network (ANN) is another powerful stochastic method for abnormal situation management. ANN has the ability of heuristic causal reasoning ability, which assists in analyzing unnoticed process variables.

Summary

Abnormal situation management is a very broad topic, involving equipment, people, management, and processes. In the field of process design and operation, we can make the process control system/safety instrumented system more intelligent and more predictive.

Because of the complex nature of chemical processes, both deterministic methods (dynamic modeling) and stochastic methods (statistical analysis) are needed in the tool kit for abnormal situation management. To detect the onset of abnormal situations, dynamic modeling provides control of the most significant process variables, while stochastic methods respond to other important but unnoticed process variables.

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[1] Peter Andow, *IEE Colloquium (Digest) Proceedings of the 1997 IEE Colloquium on Stemming the Alarm Flood*, Jun 17 1997, n 136, London, UK

[2] Edward L. Cochran, Chris Miller, and Peter Bullemer, *Proceedings of the 1996 IEEE National Aerospace and Electronics Conference, NAECON. Part 2*, May 20-23 1996, vol 2, Dayton, KY, USA

[3] Dave Harrold, *Control Engineering*, v 45, no12, Sept 1998